Memorandum

Jacobs

Slope risk assessment for Gardens of Stone Multi-Day Walk

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Project name:	Blue Mountains Geotechnical Services
Project no:	IA324500
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1. Introduction

NPWS engaged Jacobs Group (Australia) Pty Ltd (Jacobs) to undertake geotechnical site inspections and develop a quantitative slope risk assessment (QRA) for the under-construction Gardens of Stone Multi-Day Walk in the Wolgan Valley, approximately 10 km north of Lithgow.

The objective of the investigation is to develop a quantitative risk assessment (QRA) of life risk from landslide hazards along the track, and then classify the risk using the tolerability thresholds adopted in the NPWS *Landslide and Rockfall Procedures* (2019, 2024). This QRA considers life risk in terms of societal risk to walkers after the track is completed, and also individual risk to workers undertaking track construction works.

Risk remediation strategies are developed in accordance with the *ALARP* principle, which tests whether risks have been reduced *As Low As Reasonably Practicable*. The *ALARP* principle is a qualitative measure to assess that no further risk reduction would be possible without disproportionate cost, environmental impacts, or risk to workers undertaking the remediation activities, relative to the level of risk reduction that is achieved.

The outline of this memorandum is summarised below:

- **Section 2** provides a description of the project area including a review of the regional setting, geology, and topography, focusing on their influence on slope failure processes that produce landslide hazards that can impact the track alignment.
- **Section 3** presents relevant observations from Jacobs' September 2024 site inspections, including trackside observations of slope hazards and close inspection of 3D photogrammetry models that produced from remotely piloted aircraft (RPA) photography collected during the site inspections.
- **Section 4** presents a desktop GIS assessment of landslide susceptibility for the project area. The results are used to identify track segments subject to higher relative risk, and provide preliminary guidance for selection of QRA parameters including the annualised probability of landsliding.
- **Section 5** presents the QRA inputs and results including (1) a societal risk assessment for visitors after the track is opened; and (2) an individual risk assessment for track construction workers.
- **Section 6** provides risk mitigation recommendations for the inspection sites.

Appendix A contains the complete set of QRA spreadsheets for societal risk and individual risk assessment; and **Appendix B** contains supplementary GIS maps of the project area, developed as part of the desktop GIS landslide susceptibility assessment.

This work has been undertaken in accordance with Jacobs' variation proposal dated 14 August 2024, and the terms and conditions set out in contract PROC 9833 and corresponding Purchase Order 4500966236.

2. Site Description

2.1 Regional Setting

Gardens of Stone Multi-Day Walk is in the Wolgan Valley, approximately 10 km north of Lithgow. Figure 2-1 shows a global plan view of the topography surrounding the project area. The track alignment is approximately 25.2 km long and it is divided into three sections as shown. Indicative chainage markers are shown at 500 m intervals for reference, beginning at the southern terminus of Section 1.

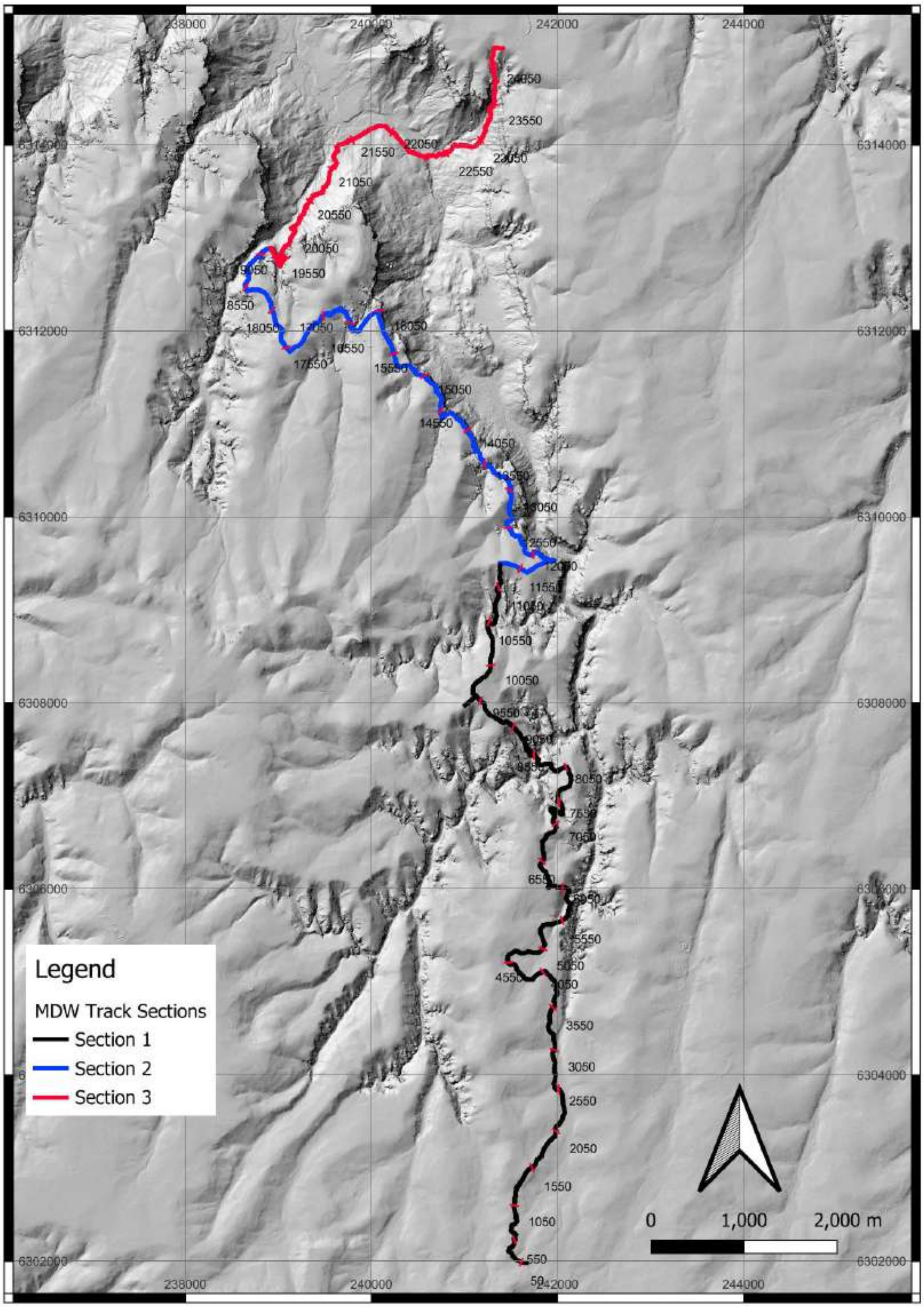

Figure 2-1: Global plan view of Multi-Day Walk alignment

2.2 Geology and Physiography

An appreciation of the regional geological setting is a critical first step in understanding the landslide hazards that pose a risk to the site. Figure 2-2 shows a plan view of key geological units in the project area, extracted from the NSW *Seamless* Geology dataset (Colquhoun et al., 2021).

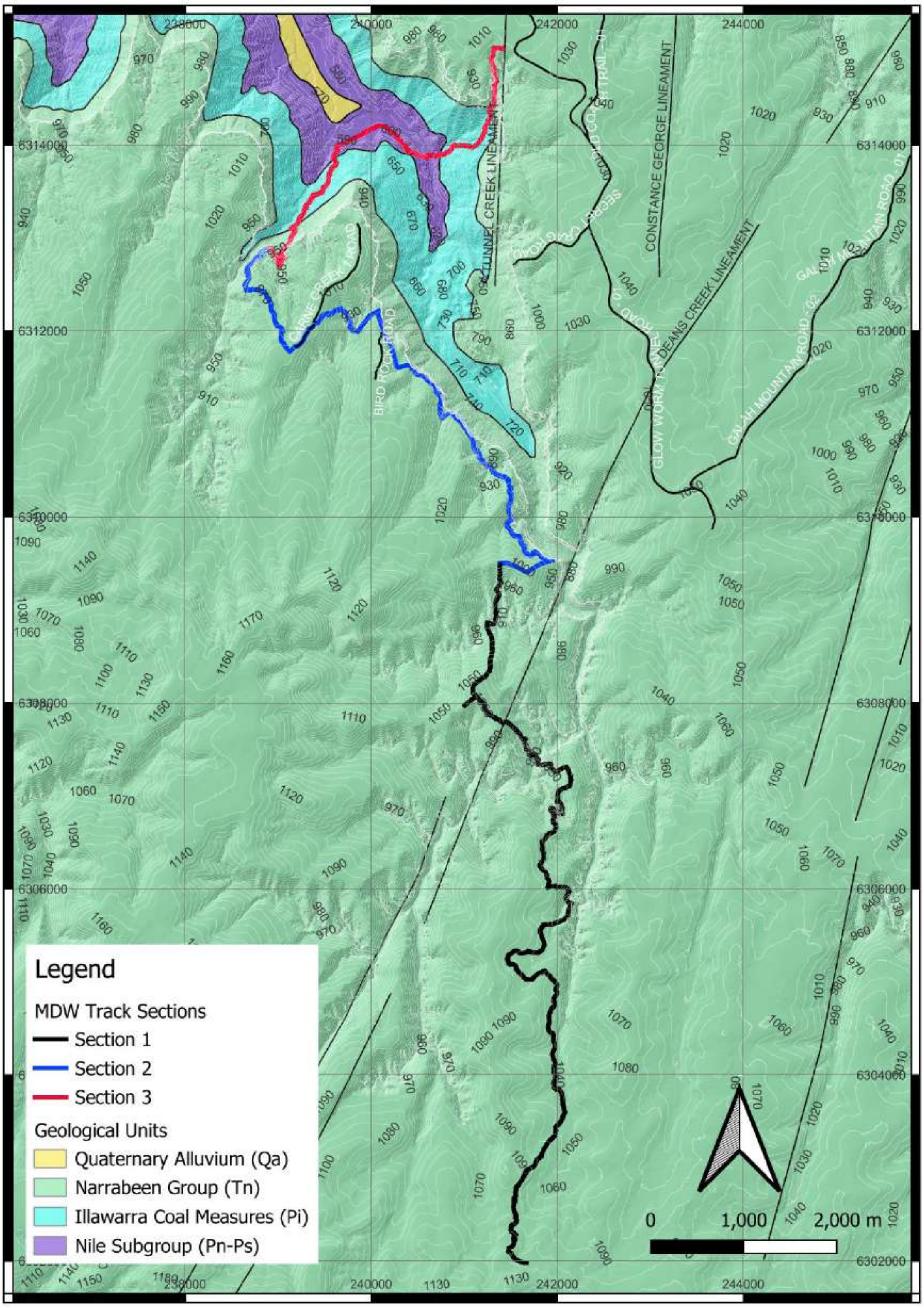

Figure 2-2: Geological plan of the project area

The project area is near the western margin of the Sydney Basin, a geological province comprising horizontal to shallow dipping sedimentary rocks, which in the project area comprise interbedded sequences of Triassic age Narrabeen Group sandstones deposited in fluvial and deltaic environments capping the top of the escarpment, underlain by the Permian age Illawarra Coal Measures, which comprise shales, claystones, and coal deposited in lower energy meandering river systems, brackish shallow seas, coastal swamps and lagoons. Figure 2-3 shows an annotated plan and isometric view of the cliffs above the western half of track Section 3, showing the indicative boundaries of key geological units.

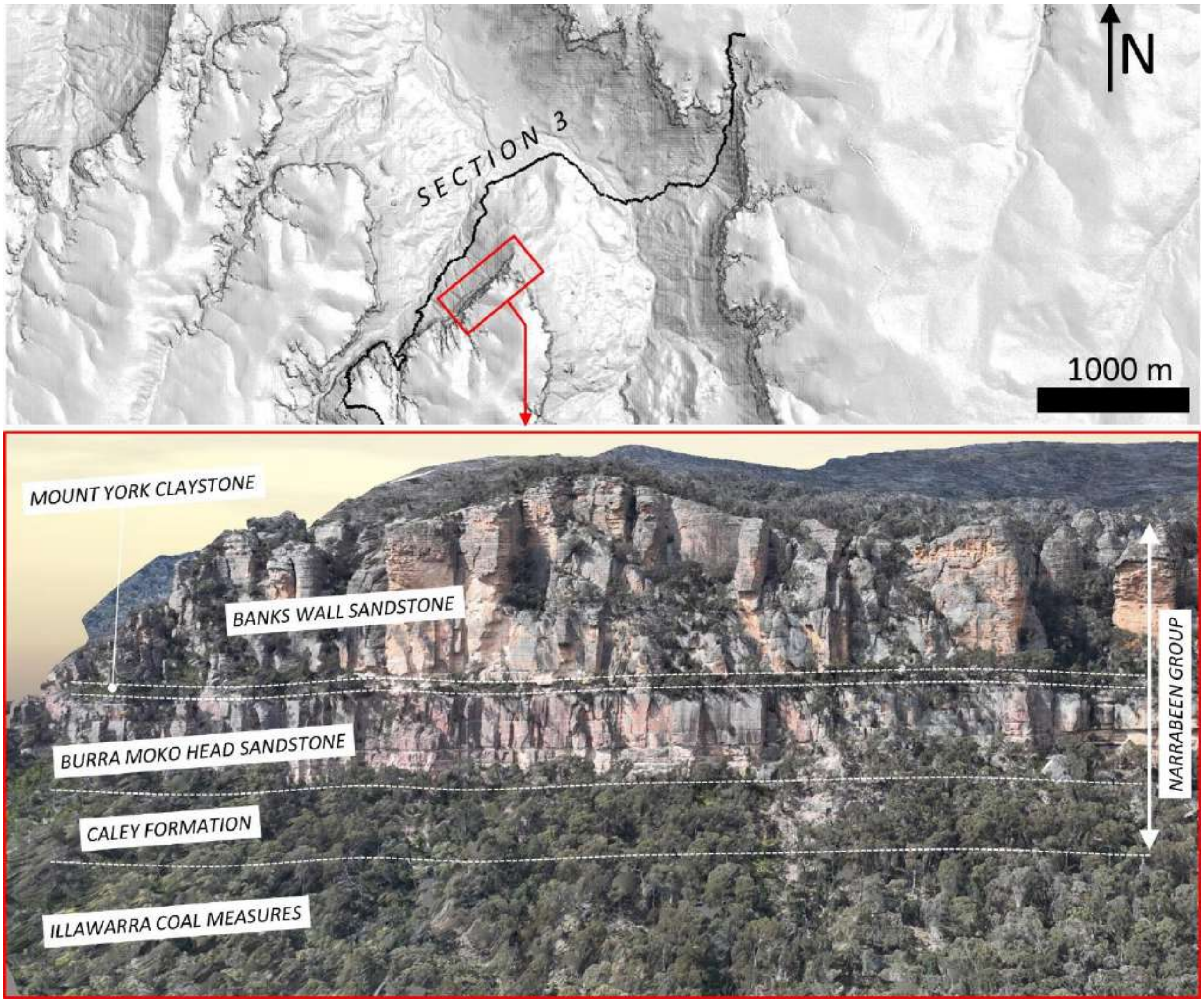

Figure 2-3: Plan and annotated photogrammetry image showing indicative geological unit boundaries

The upper escarpment cliffs are formed of the Triassic age Banks Wall Sandstone, belonging to the Grose Subgroup of the Narrabeen Group. The Banks Wall Sandstone comprises massive, quartzose sandstone with frequent ironstone bands and occasional conglomerate and claystone lenses; the unit is locally up to 120 m thick. The rock mass structure of the Banks Wall Sandstone is characterised by sub-horizontal bedding discontinuities, and two systematic sets of widely spaced, very high persistence sub-vertical joints that developed during the process of lithification, uplift, and exhumation. The two main joint sets are regionally ubiquitous and roughly orthogonal to each other: around the project area one joint set trends NNW-SSE, and the second set trends ENE-WSW. Combined with the sub-horizontal bedding, these three sets of structural discontinuities produce cubic to tabular shaped blocks of sandstone that can become kinematically free to detach and fall from the cliffs; the cubic to tabular shape of rockfall blocks deposited across the talus slopes below the cliffs are further evidence of this typical structural control on rockfall failure.

The Banks Wall Sandstone is underlain by the Mount York Claystone, a marker unit of low strength red-brown kaolinitic claystone that that forms a continuous bench in the middle of the cliffs for kilometres across the escarpment. The lower cliffs below the Mount York Claystone are formed by the Burra-Moko Head Sandstone, an early Triassic quartzose to quartz-lithic sandstone that is underlain by interbedded claystone, shales, and quartz-lithic sandstones of the Caley Formation, which forms the basal unit of the Narrabeen Group and the Permian-Triassic boundary. Underlying the Caley Formation is the late Permian Illawarra Coal Measures, comprising interbedded layers of pebbly sandstone, coal, conglomerate, mudstone, carbonaceous claystone and torbanite (oil shale). This unit is typically buried under the apron of talus and colluvium that covers the valley side slopes.

The topography of the site is characteristic of the Wolgan Valley and the wider Blue Mountains region. The Newnes Plateau that surrounds the Wolgan Valley is an uplifted sandstone tableland that has been deeply incised by rivers, with cliffs typically 200 m high surrounding the valley rim. Figure 2-4 shows a regional plan view of a 2 m resolution digital elevation model (DEM) for the project area compiled from publicly available data, coloured by elevation and highlighting the planned track sections. The maximum elevations of up to 1100 m AHD occur along track Section 1 and Section 2, which traverse the western side of the valley above Carne Creek. Section 3 connects the west and east sides of the valley, reaching a minimum elevation of approximately 580 m AHD at the creek crossing in the centre of the valley.

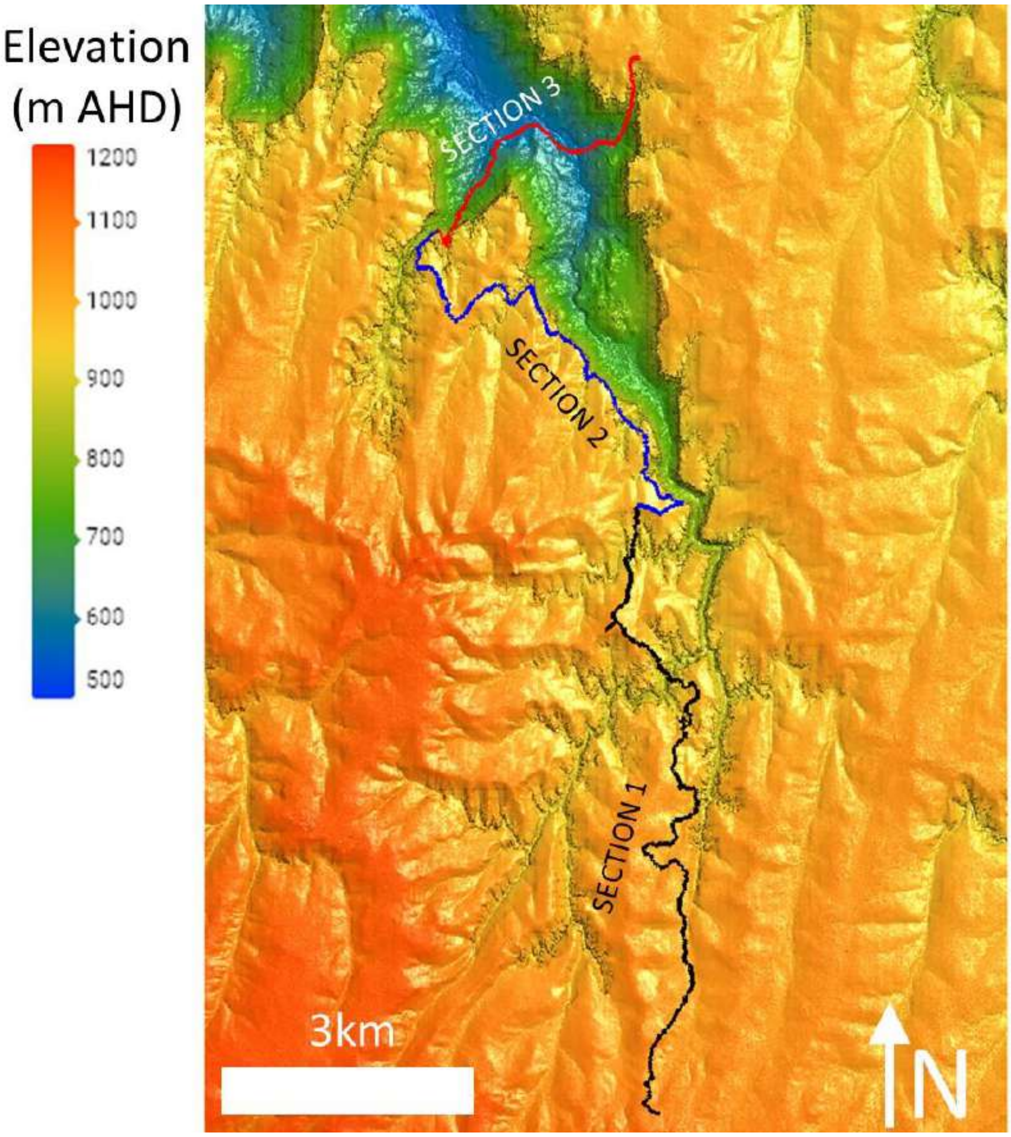

Figure 2-4: Plan view of regional DEM coloured by elevation

The dominant topographic feature is the extensive subvertical escarpment cliffs and the steep apron of talus that has accumulated on the slopes that fringe the base of the cliffs. Figure 2-5 shows an isometric view of the project area DEM centred on Section 3, where the eastern and western ends of the track connect the top of the escarpment to the valley below. Zones of higher rockfall risk cover the sections of track that pass directly under the vertical escarpment cliffs.

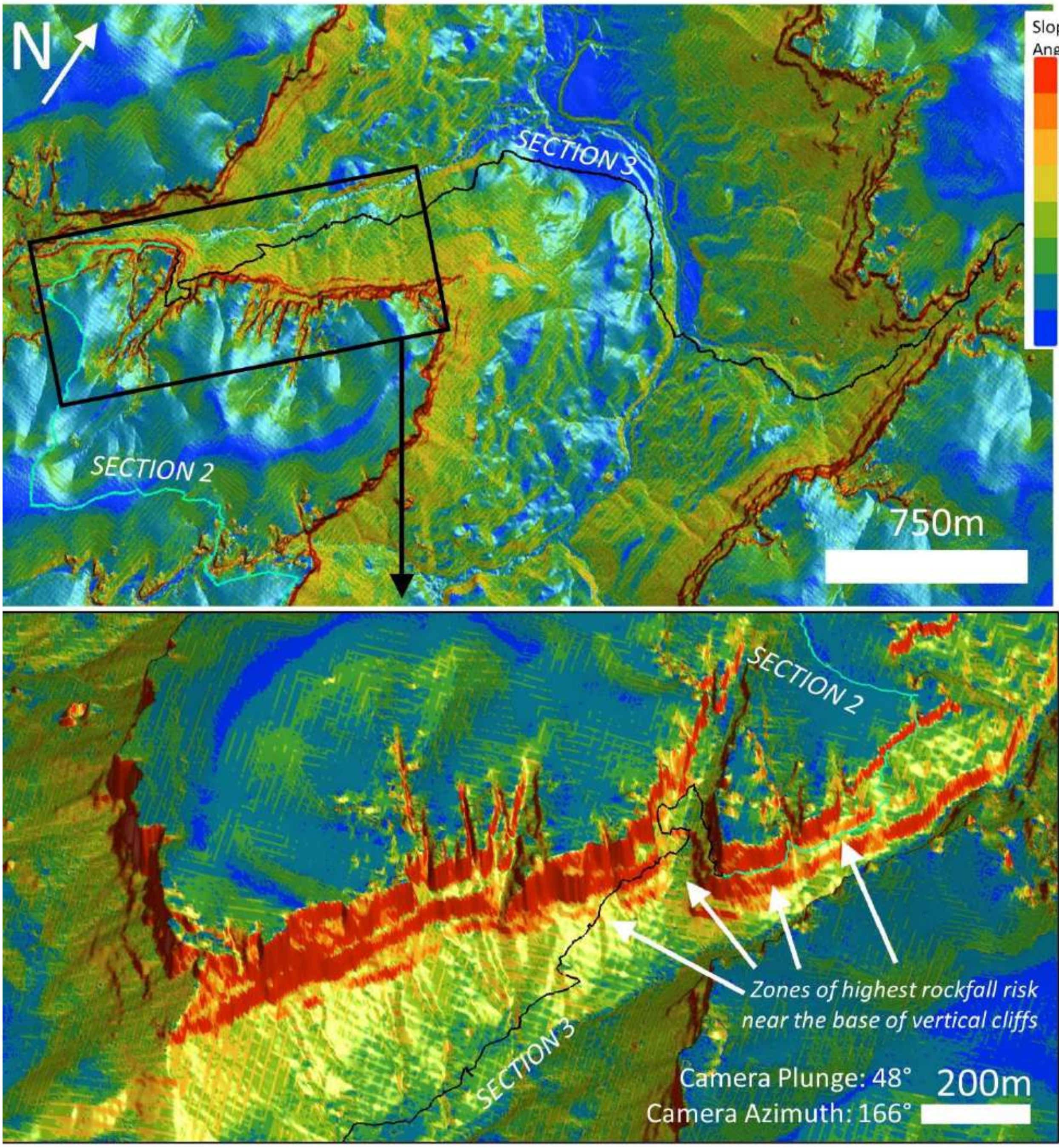

Figure 2-5: Plan view of regional DEM coloured by slope angle

Section 4 presents a desktop GIS-based assessment of landslide and rockfall susceptibility, based on a combination of slope steepness and rockfall “shadow angle” which represents the location of the walking track with respect to the cliffs.

2.3 Slope Failure Mechanisms

Adopting a framework for landslide classification is a prerequisite to slope risk assessment. Figure 2-6 shows an accepted landslide classification scheme based on material type, movement style and velocity, highlighting some of the most common landslide mechanisms observed in the Blue Mountains.

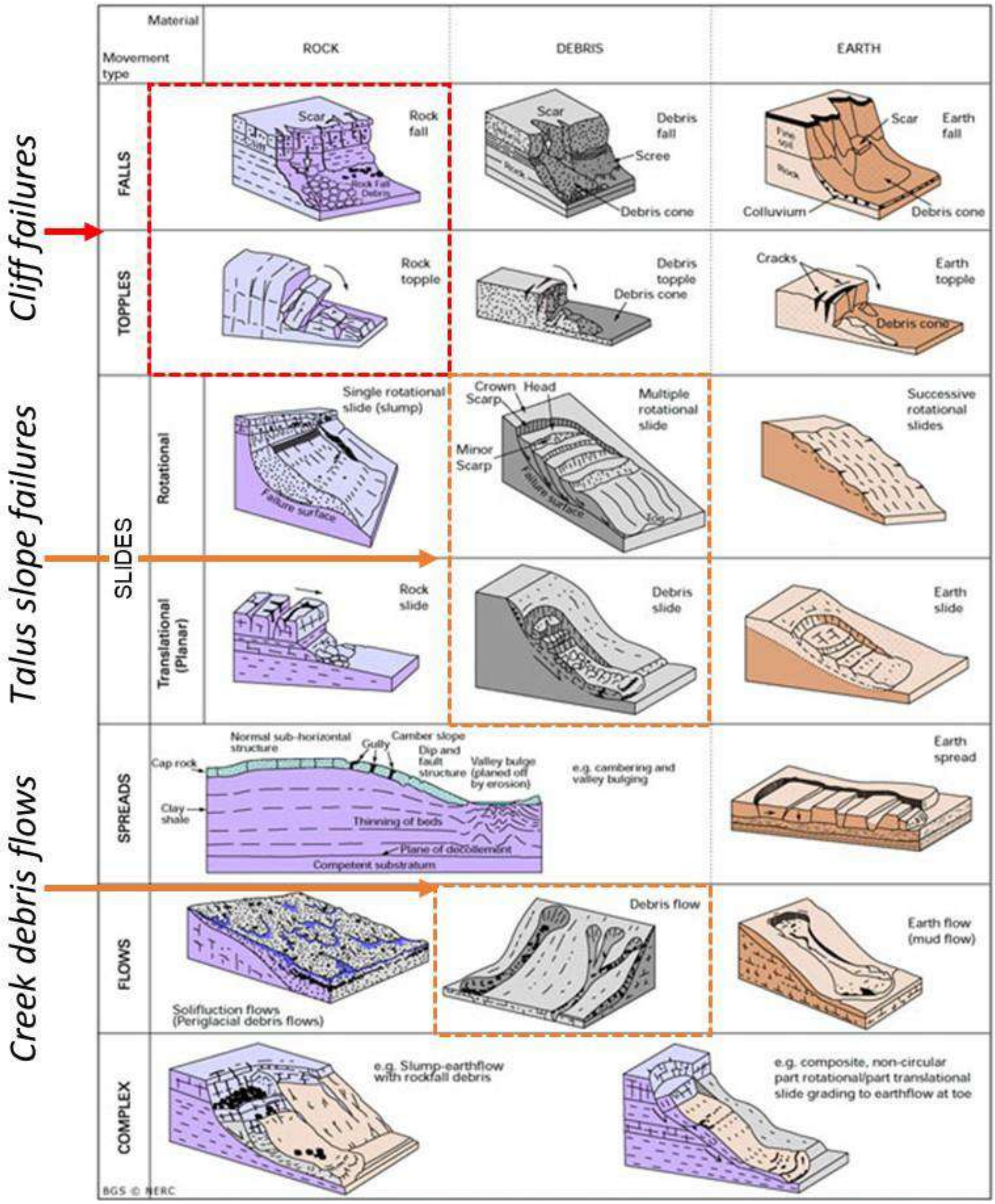

Figure 2-6: Landslide classification by material and movement type

Source: Adapted from Varnes (1978), Cruden and Varnes (1996); and the British Geological Survey

2.3.1 Rockfalls

Rockfalls commonly initiate as toppling, planar sliding, or wedge sliding failures, involving discrete blocks that dislodge from the cliff face along a combination of pre-existing discontinuities in the rock mass, and sudden brittle failure of intact rock bridges. Larger rockfalls may entrain additional material when they impact the slope, creating rock or debris slides that run out into the valley below. Where walking tracks pass directly under natural or excavated overhangs, slabs of sandstone may detach along bedding partings, falling just a few metres directly onto the track. Rockfall initiation may be promoted by tree root jacking within pre-existing fractures, elevated pore pressures from intense rainfall events, or may simply occur with no obvious external trigger, as the culmination of slow, long-term crack growth driven by gravitational stresses.

Figure 2-7 shows a conceptual illustration of common rockfall processes that occur in bedded sandstone rock masses undermined by weaker shale or claystone. The resulting slope morphology produced by long-term rockfall is characterised by steep upper cliff faces formed by a weathering-resistant upper sandstone unit, with an apron of talus or scree deposited on the valley slopes below, burying the underlying shale or coal measures rocks of the Illawarra Coal Measures.

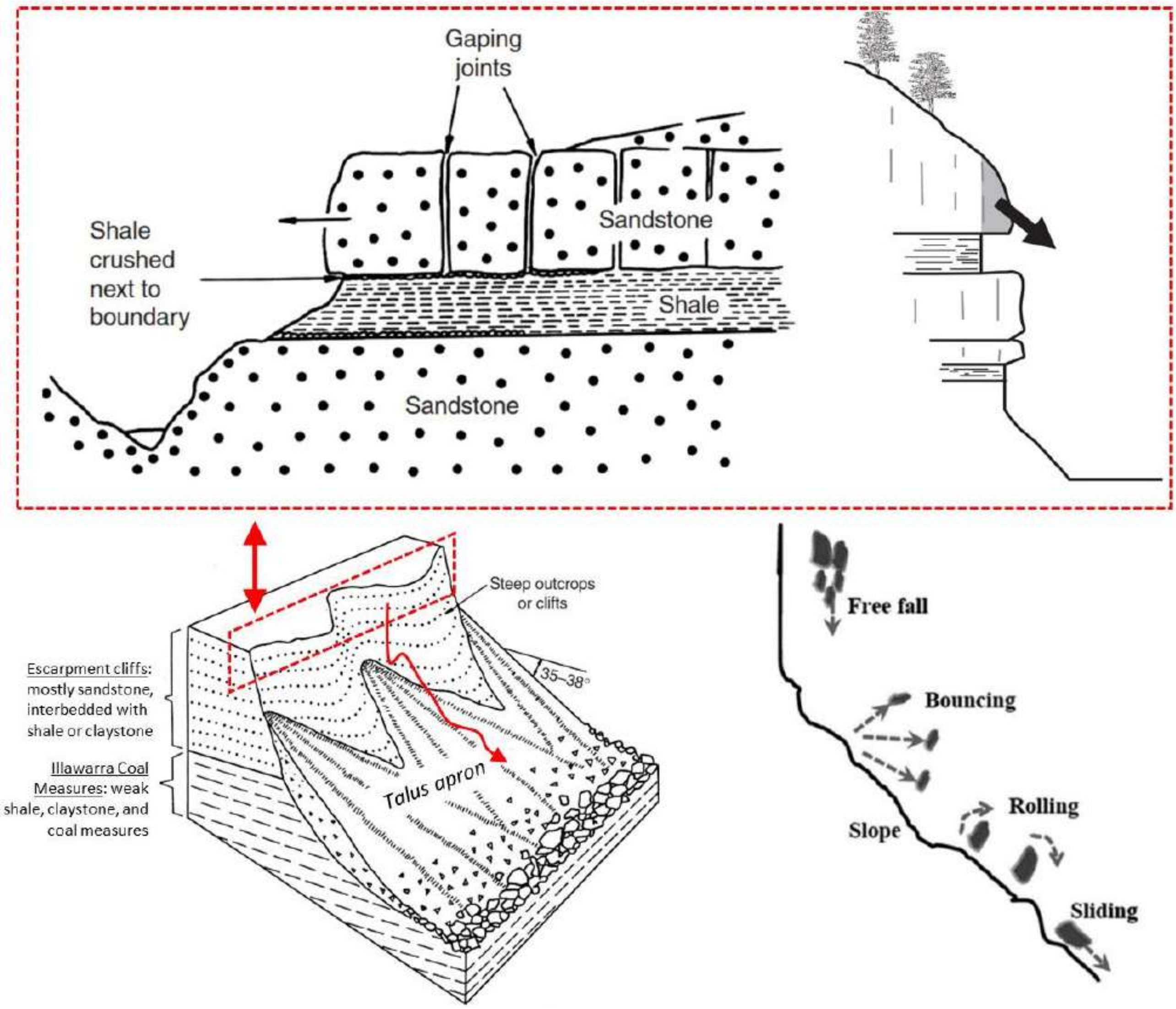

Figure 2-7: Examples of rockfall processes, associated landforms and runout motion

Source: Adapted from Wyllie and Mah (2004); Fell (2005); and Basson et al. (2015)

Significant rockfall runout distances typically requires a slope angle of at least 35° with transport involving a combination of free-fall and bouncing on the initial impact, transitioning to rolling and sliding as the block moves downslope. The travel distance can be characterised in terms of a “travel angle” or Fahrböschung, which represents the inclination of a line projected from the rockfall source on the cliff face, to the furthest observed runout block. The travel angle concept is critical to chacterising the extent of the “rockfall shadow” of the escarpment cliffs, representing the zone at the base of the cliffs that is exposed to potential rockfall impacts. The “rockfall shadow” concept forms a key input to the GIS assessment of landslide susceptibility.

International case studies from varied geological settings show that rockfall size tends to follow a negative exponential or logarithmic magnitude-frequency relationship: this means that smaller rockfalls occur much more frequently that larger events (Hungr et al. 1999). Block size depends on geological structure (spacing of pre-existing discontinituies in the rock mass), and travel distance depends on block size and shape, as well as the morphology of the slope and the presence of vegetation (i.e. trees and undergrowth).

Typically, a new rockfall is reported somewhere on a track in the Blue Mountains about once a month. These events likely represent a small fraction of all rockfalls. Many more rockfalls likely occur in remote areas away from tracks and roads. Furthermore, some fraction of rockfalls occurring near walking tracks and roads can be expected to either overshoot the track or come to rest on the slopes above, and thus go undetected. Figure 2-8 shows a selection of reportable rockfalls around the Blue Mountains dating back to 2020.

Figure 2-8: Examples of sandstone rockfalls reported in the Blue Mountains between 2020 and 2022

Estimating the magnitude-frequency relationship of rockfalls is a critical early step in the QRA, where we must define how often a rockfall of a given size is expected to occur.

2.3.2 Debris and Rock Slides

Debris and rock slides involve displacement of the failure mass along a basal sliding surface. Debris slides commonly occur on the talus slopes or in the "hanging swamps" and wetlands around the rim and middle benches of the escarpment. These slides may be triggered by periods of intense rainfall or prolonged wet periods that cause the soil to become saturated and reduce its effective shear strength. Failures may comprise a mixture of mud, boulders, and vegetation that can creep slowly downslope, or fluidise and move very rapidly if pore pressures become sufficiently elevated to induce undrained shear failure. Figure 2-9 shows conceptual cross sections of debris slides that fail along the interface between colluvial soil or completely weathered (soil strength) material and the underlying bedrock.

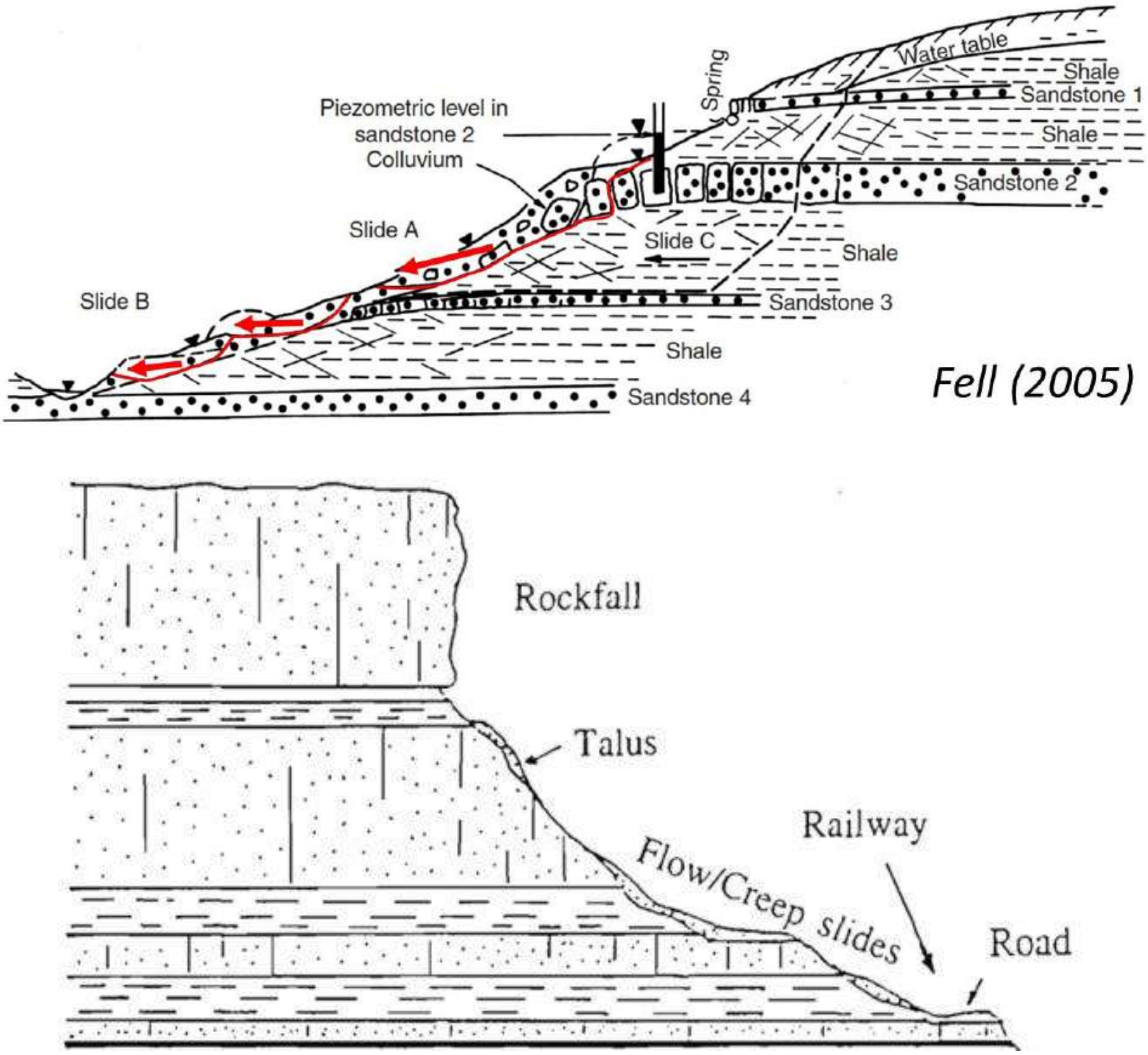

Figure 2-9: Possible earth or debris slide mechanisms initiating in colluvium or talus slopes

Source: Fell (2005); and Ghobadi (1994)

Whereas debris slides tend to be shallower failures, rock slides involve deeper-seated failure through the underlying rock mass, and therefore these failure mechanisms tend to involve much larger volumes than typical debris slides. There is evidence of modern and ancient rock slides in Blue Mountains National Park. A modern example involves a multi-lobe rock slide that occurred on the southern flanks of Mount Solitary in early 2022, likely triggered by sustained heavy rainfall during La Niña. The basal sliding surface extends beneath the talus slope and into the underlying weathered rocks of the Illawarra Coal Measures, with an estimated failure volume in the hundreds of thousands of cubic metres (Figure 2-10).

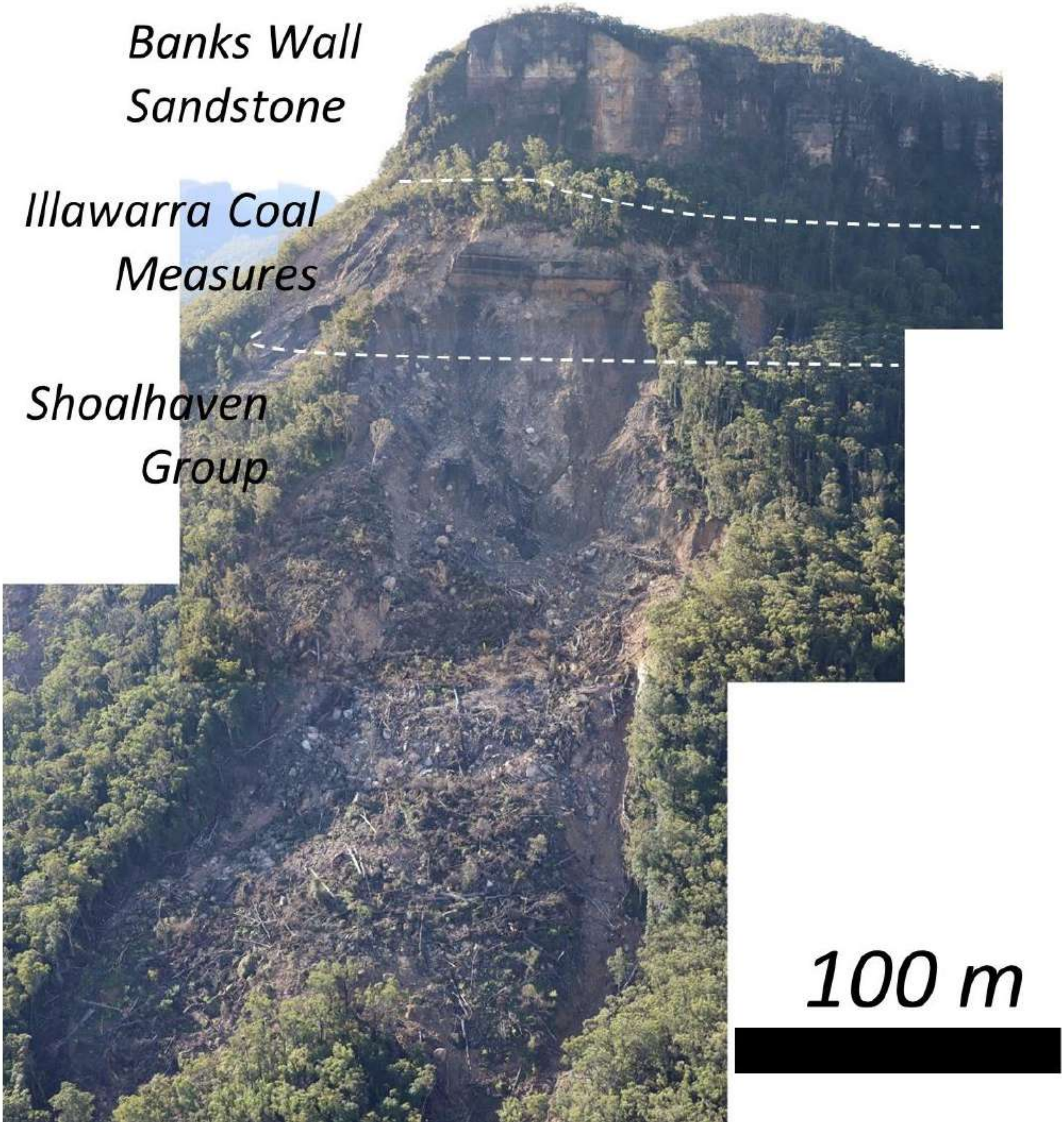

Figure 2-10: Large multi-lobe debris slide at Mount Solitary that occurred in early 2022

Hatherly and Brown (2022) provide a comprehensive discussion of landforms and geology of the Blue Mountains. In the chapter covering the Newnes Plateau and Wolgan Valley, the authors described the largest example of an ancient landslide occurring at Carne Creek, across the valley from Section 2 of the multi-day walk. The Carne Creek landslide involved collapse of a one kilometre length of cliff, with an estimated failure volume of 30 million cubic metres. Figure 2-11 highlights the landslide area on the publicly available DEM.

The authors estimated that failure occurred 13,000 years ago based on a "dated sample" (details are not provided as to the sample type and dating methodology). The slide was large enough to divert Carne Creek to the western side of the valley, towards its present course. The debris probably created a landslide dam that the creek subsequently eroded and breached. Boulders in the runout zone have edge length in the tens of metres. The Carne Creek landslide highlights the potential for very large rock slides in the project area, albeit with very long return periods exceeding 10,000 years.

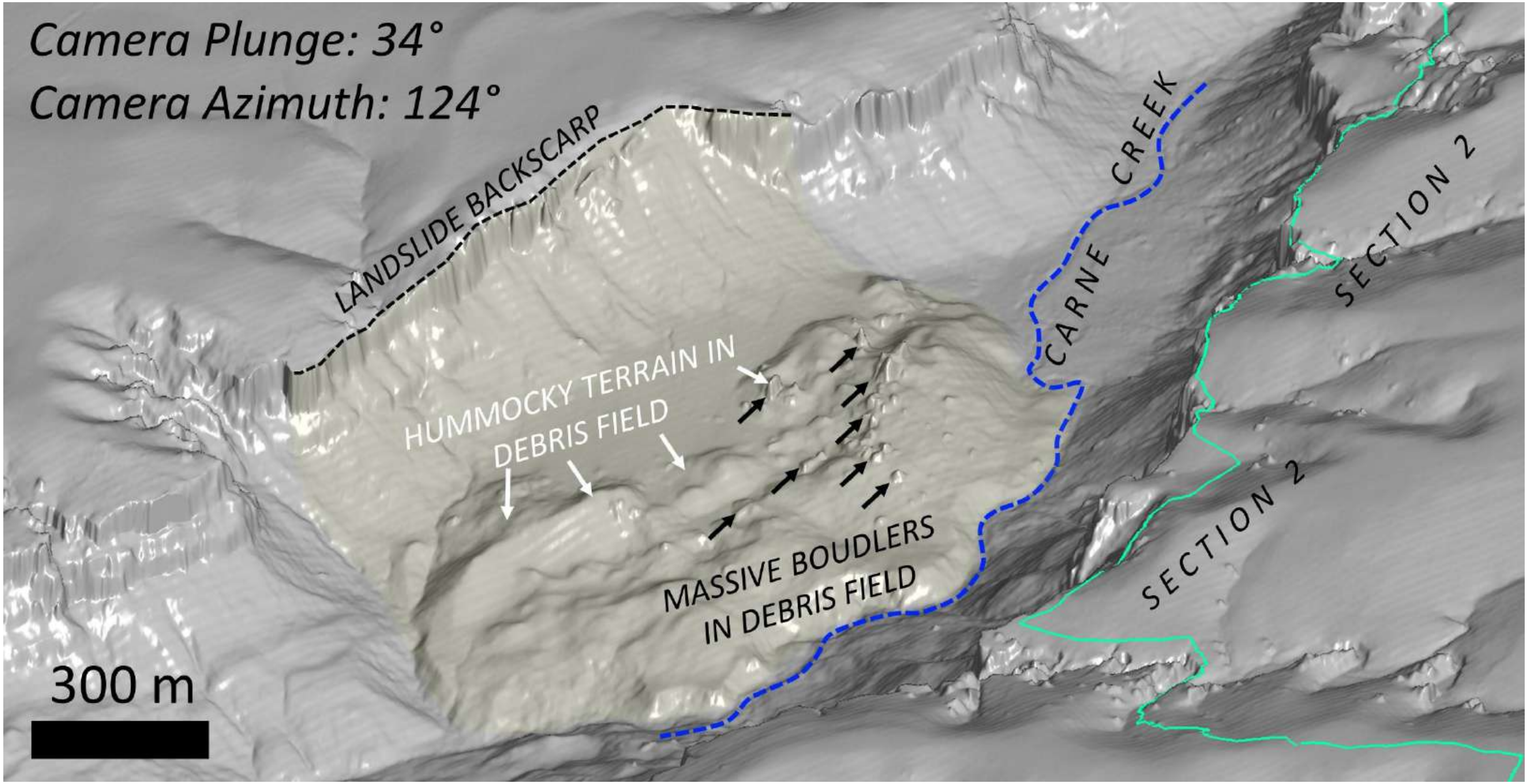

Figure 2-11: Isometric view of site DEM highlighting the ancient Carne Creek landslide

3. Site Inspection Observations

3.1 Inspection Summary

Representatives from Jacobs and NPWS completed four days of site inspections between 10 and 13 September 2024, focussing on selected track sections that are expected to have the highest relative landslide risk. Figure 3-1 shows a plan view map highlighting the extents of the walkover inspections.

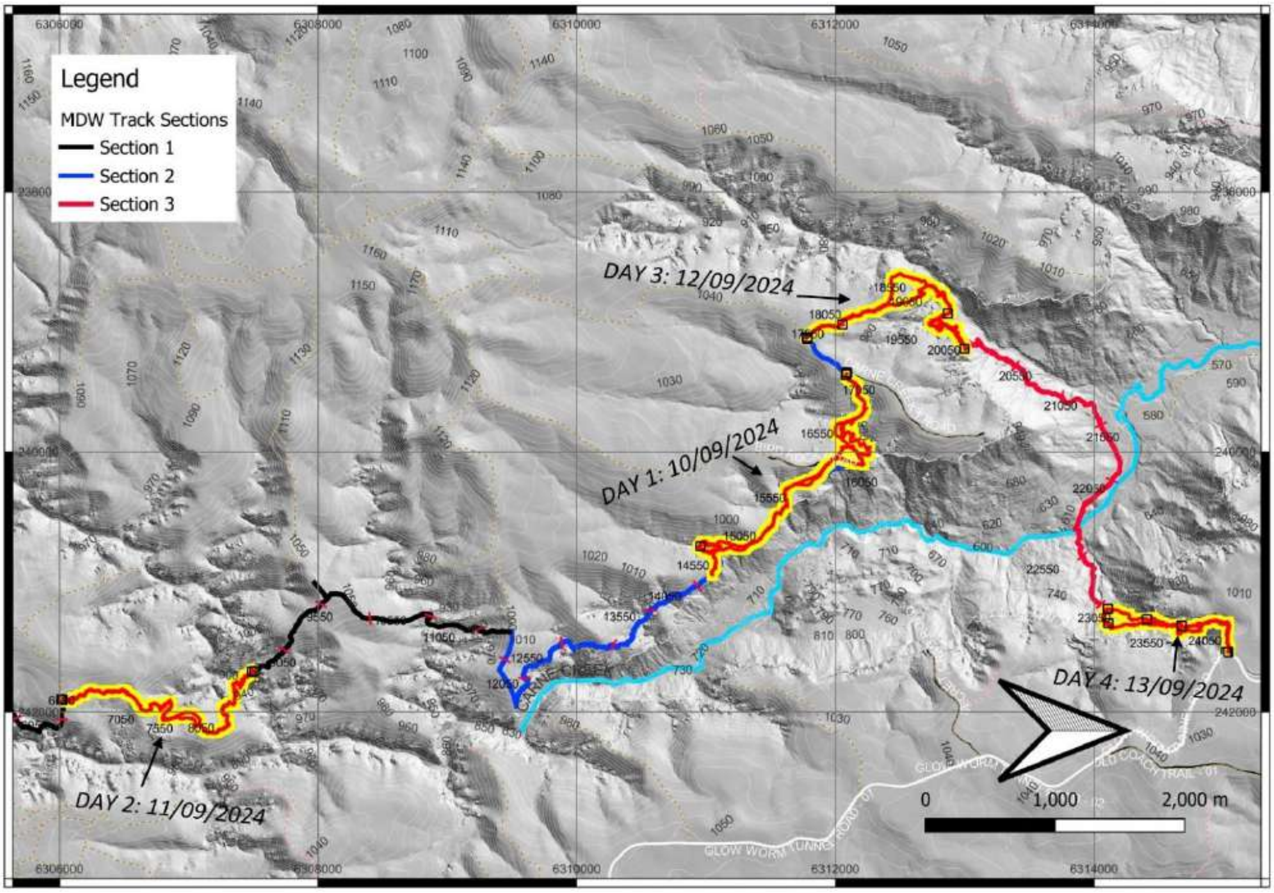

Figure 3-1: GIS plan highlighting extents of site walkovers

Key details of each day of inspections are summarised below in Table 3-1.

Table 3-1: Summary of site inspection details

Date	Inspection Extents (Chainage)	Description
10/09/2024	Section 2 *(14.2 km to 17.2 km)*	Mostly traverses gentle terrain along the top of the escarpment. Creek crossing at chainage 16.5 km has rockfall potential.
11/09/2024	Section 1 *(6.2 km to 8.7 km)*	Mostly traverses gentle terrain along the top of the escarpment. Crossing at chainage 8.6 km (Carne Creek); track ascends a narrow “slot” feature with potential rockfall.
12/09/2024	Section 3 West *(17.5 km to 20.1 km)*	Western descent into Wolgan Valley traverses passes directly under high cliffs with very high potential for rockfall impact.
13/09/2024	Section 3 East *(23.1 km to 24.2 km)*	Eastern descent into Wolgan Valley through a steep gully with high cliffs above and high rockfall potential for rockfall impact.

3.2 Section 1

The inspection of Section 1 focused on an area of expected high rockfall risk on the north side of Carne Creek crossing. The track ascends a narrow "slot" feature with potential rockfall sources on cliffs surrounding the slot. Figure 3-2 highlights the track alignment at the time of inspection, passing through the narrow slot feature, and nominates a potential alternate route that would reduce track susceptibility to rockfall impact. The QRA in Section 5 considers risk to life for current track alignment shown in red above

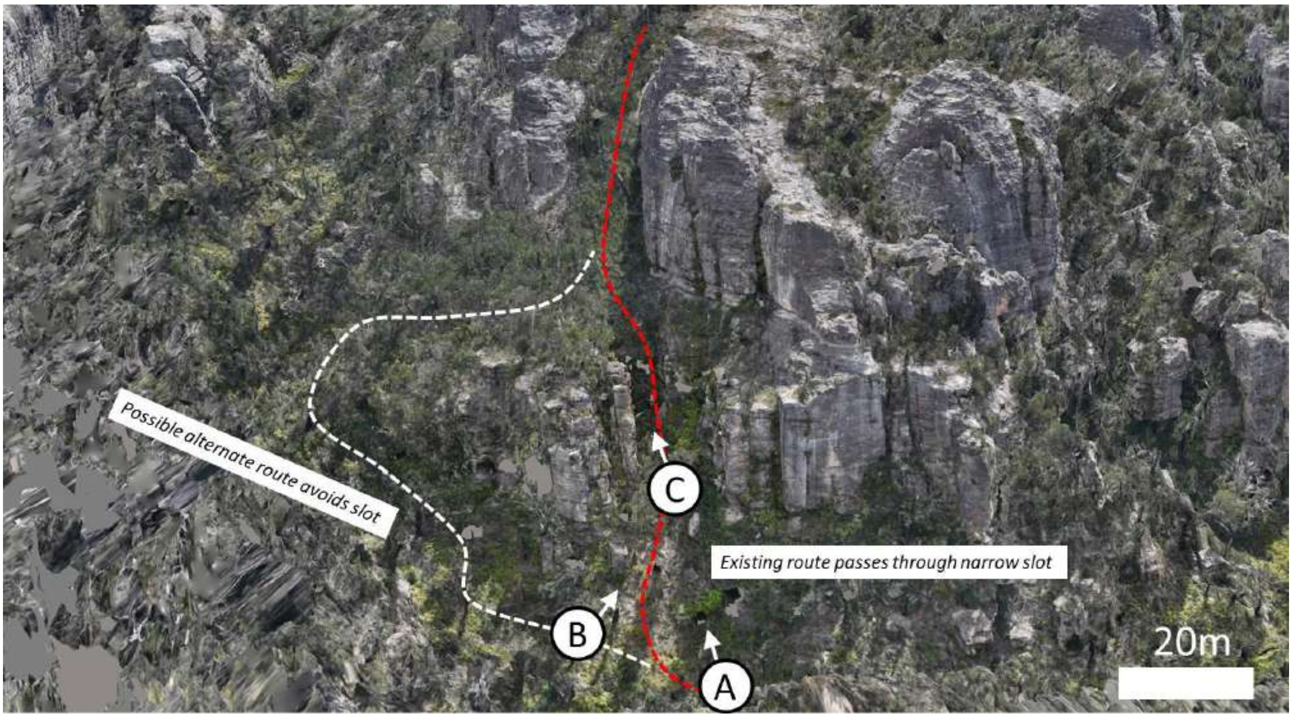

Figure 3-2: Section 1 main rockfall hazard area (extracted image from photogrammetry model)

Figure 3-3 shows trackside photographs of rockfall hazards at locations A, B, and C. Hazards that could impact the track include toppling and planar sliding failures initiating from the cliffs on both sides of the "slot" feature. Furthermore the "slot" features acts as a funnel, such that rockfalls impacting the upper slope are likely to be directed downslope, potentially impacting the walking track alignment at multiple locations. .

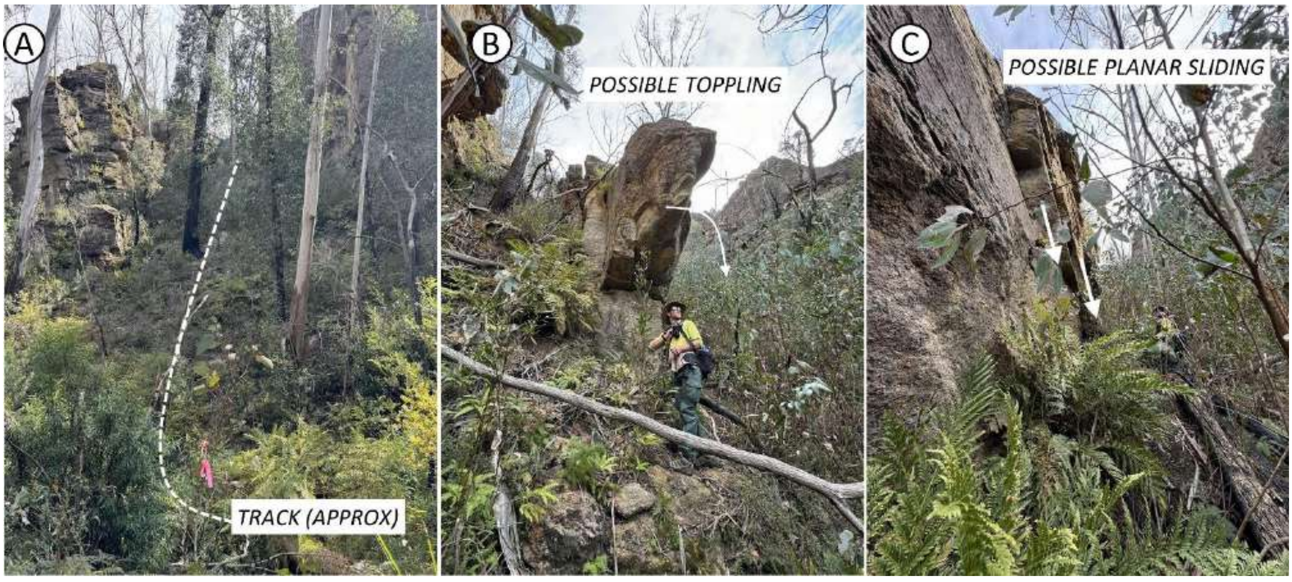

Figure 3-3: Trackside photographs of rockfall hazards in Section 1 above Carne Creek crossing

3.3 Section 2

The inspection of Section 2 covered an area of generally low rockfall susceptibility, spanning sections of track that traverse along the top of the escarpment. Sections of track along the top crest of the escarpment have no potential for rockfall impact from above: possible landslide impacts for these areas are limited to large-scale, long return period cliff collapse events such as the Carne Creek landslide described in Section 2.3; these could involve loss of the track for sections that approach close to the edge of the cliff.

The main area of potential rockfall impact occurs at a planned gully crossing near chainage 14.5 km, where the approach to the creek crossing passes below vertical sandstone cliffs with height limited to about 15 m above track level. Figure 3-2 shows a plan view of the location.

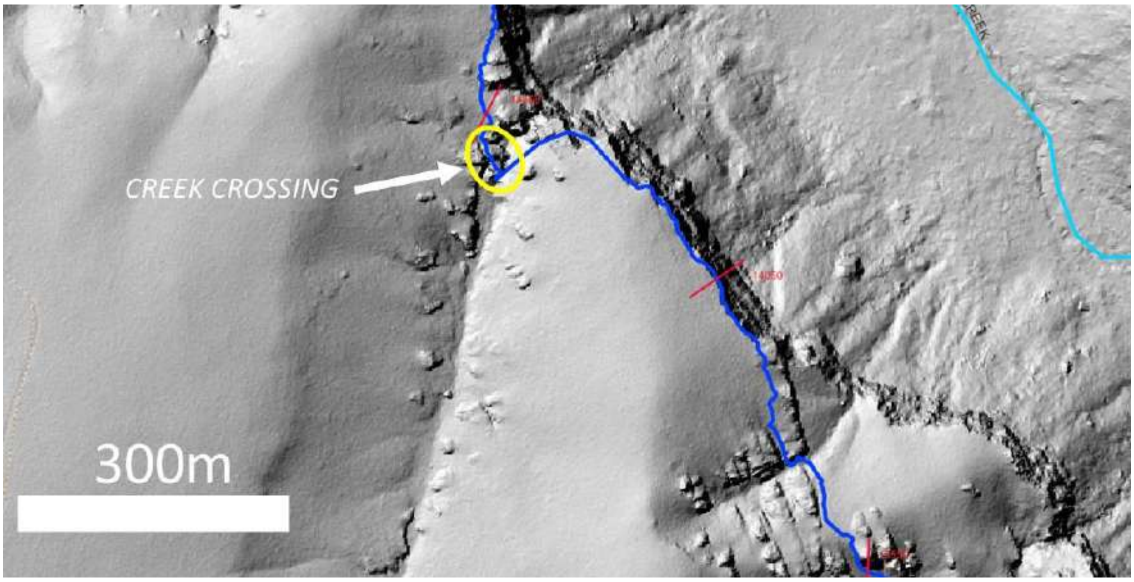

Figure 3-4: Section 2 main rockfall hazard area (extracted image from photogrammetry model)

Figure 3-5 shows trackside photographs of the creek crossing area; a planned staircase or bridge structure will span approximately 3 m between the escarpment cliff and massive detached sandstone boulder that spans the gully. The main rockfall risks relate to potential wedge sliding or planar sliding of discrete blocks over an approximately 30 m long section of track on the western approach to the creek crossing.

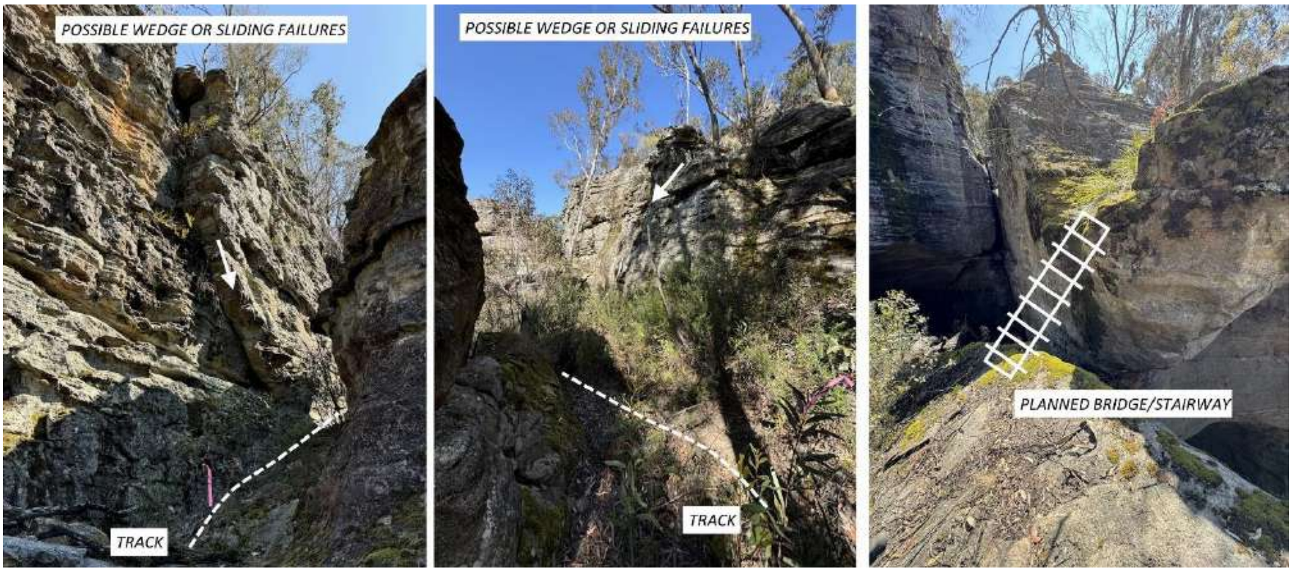

Figure 3-5: Trackside photographs of rockfall hazards in Section 2 above unnamed creek crossing

3.4 Section 3

Section 3 contains the sections of track with the highest overall landslide susceptibility, encompassing the sections of track that connect the top of the escarpment to the valley below. Figure 3-2 shows a plan view of the site highlighting the zones of highest relative risk, where the tracks pass directly below the escarpment cliffs within the “rockfall shadow” where probability of impact is near certain. The map is coloured according to the GIS based assessment of landslide susceptibility, that is discussed further in the next section.

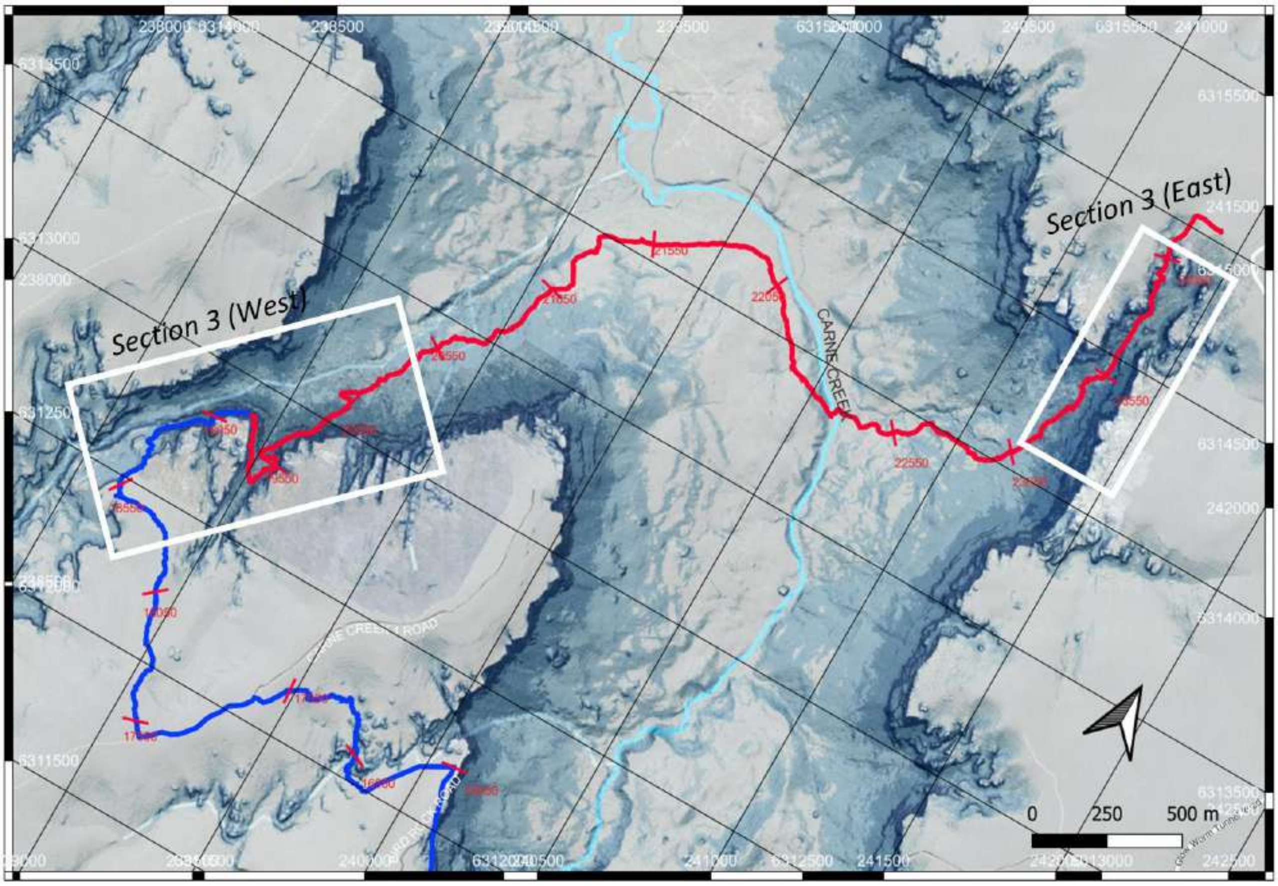

Figure 3-6: Plan view of highest landslide risk areas in Section 3

Figure 3-7 shows an annotated isometric view of Jacobs’ RPA photogrammetry model for Section 3 (West). The locations of three specific slope hazards are marked at locations A, B, and C.

- **Location A** comprises a stack of boulders perched directly above the proposed track alignment. The boulders are detached and leaning down-slope, forming a potential toppling hazard.
- **Location B** encompases a zone of overhanging cliff above the track, spanning approximately 50 m in length. The contrast in rock colour of the cliff face indicates a zone of geologically frequent rockfall. Many potential slabs, flakes, and rock wedges are present on the cliff face above the track.
- **Location C** is the detachment scar of a recent rockfall reported by NPWS, where an approximately 20 m3 cubic block detached from the cliff face. Water was observed to be seeping from a fracture at the base of the detachment scar at a rate of over 5 L/min, indicting a likely role of groundwater pore pressures in promoting the rockfall initiation.

Figure 3-7: **Annotated view of photogrammetry model of Section 3 (West)**

Figure 3-8: Section 3 (West) hazard location A

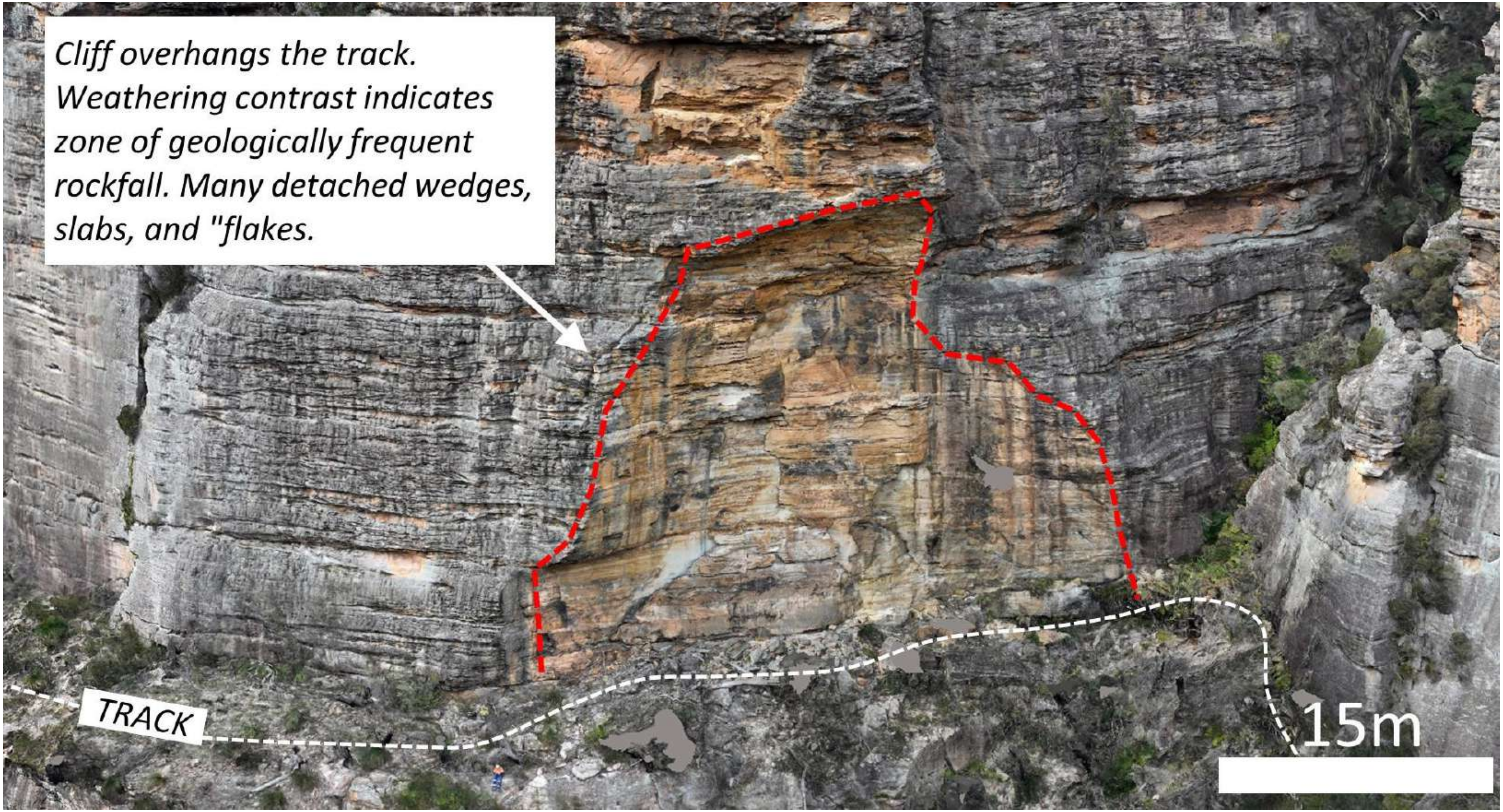

Figure 3-9: Section 3 (West) hazard location B

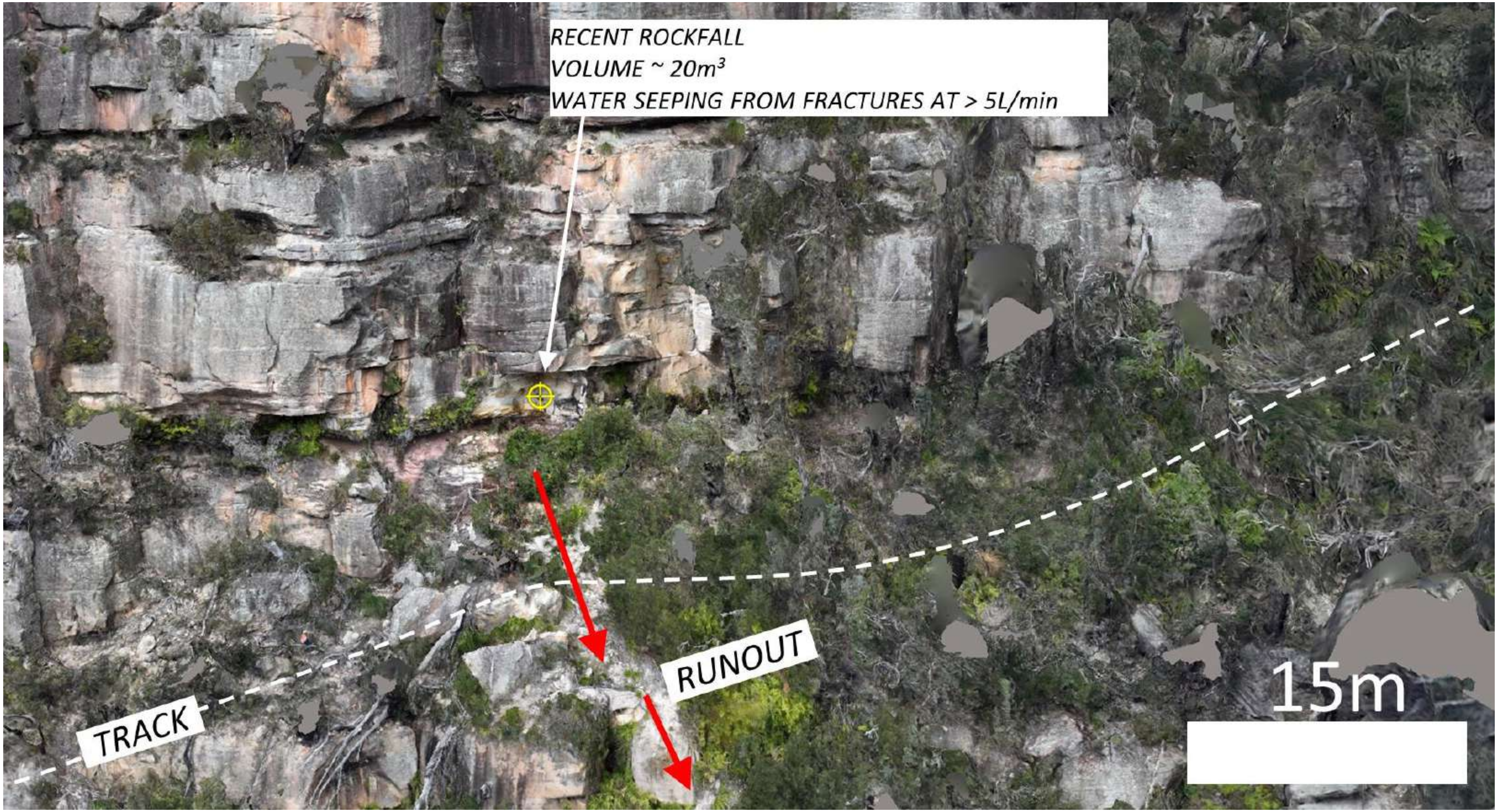

Figure 3-10: Section 3 (West) hazard location C

Figure 3-11 shows trackside photographs of hazard location A for reference. Based on the detached and tilted condition of the boulder stack, Jacobs expects that it could be removed (scaled) using conventional manual scaling techniques using pry bars, hydraulic jacks, or pneumatic inflatable airbags.

Figure 3-11: Trackside photographs of hazard location A

Figure 3-12 shows trackside photographs of hazard location B. Large “flakes” of sandstone are formed by subvertical fractures that dip sub-parallel to the cliff face. The overhanging geometry of the cliff also creates potential for free-fall of overhanging blocks that detach along horizontal bedding discontinuities. Although it may not be practical to remediate slope risk at the site (i.e. stabilise or remove potentially unstable wedges), this zone should be flagged as an area of high rockfall risk. Worker time in this area should be minimised, the track should include rockfall warning signage urging walkers not to stop when passing through area. After construction, regular inspections by NPWS staff, nominally at intervals not exceeding 12 months, should be undertaken in order to record signs of new rockfall instability, and develop a rockfall inventory that will help to better understand the expected frequency of rockfalls through this area.

Figure 3-12: Trackside photographs of hazard location B

Figure 3-13 shows trackside photographs of hazard location C. The rockfall detachment scar shows the typical expected structural control expected to produce rockfalls: blocks are formed by a combination of horizontal bedding discontinuities and two sets of regionally ubiquitous, high persistence vertical joints.

Figure 3-13: Trackside photographs of hazard location C

Figure 3-14 shows an annotated view of the photogrammetry model for Section 3 (East) highlighting two main zones of differing landslide susceptibility. The upper portion of the track passes through a confined gully or slot approximately 80 m wide, with cliffs rising on both sides. The confined geometry of this section, along with the relatively steep dip of the slope, is likely to create a funnel effect that increases the potential for larger rockfalls initiating from the cliffs to impact the track, potentially at several locations, as the blocks continue to roll down-slope.

Below the “slot” the track descends the steep talus slope, where cliffs reach heights exceeding 150 m and the talus slope dips at a typical angle of about 35° indicating potential for long-runout of rockfalls by rolling and translation. During the site inspection Jacobs observed many boulders on the talus slope with dimensions varying from a few tens of centimetres up to several metres maximum edge length.

Figure 3-15 shows a selection of trackside photographs of potential rockfall hazards observed along Section 3 (East). Common rockfall failure mechanisms involve undermining of sandstone slabs and wedges by preferential erosion of underlying weaker claystone horizons. Overhangs are common, with several areas where large slender rock “pillars” are separated from the main escarpment by subvertical joints. Potential failure mechanisms involve global pillar collapse as a long return period, low-likelihood event, along with the potential for much more frequent detachment of small blocks, slabs, and wedges from overhangs, separating along pre-existing horizontal bedding discontinuities and typically involving blocks with maximum edge length in the tends of centimetres up to the order of approximately 1 m.

At several locations in the steep gully “slot” and on the talus slope below, there are large boulders deposited from ancient rockfalls and landslides, with edge dimensions in the order of a few metres, and in some cases in the tens of metres. Some of these boulders are perched on colluvial soil (i.e. gravity-deposited granular soils) which may be subject to long-term erosion that could undermine the boulders and initiate rolling downslope. Where possible, the track alignment should be diverted to avoid the direct runout features of boulders perched immediately above the track.

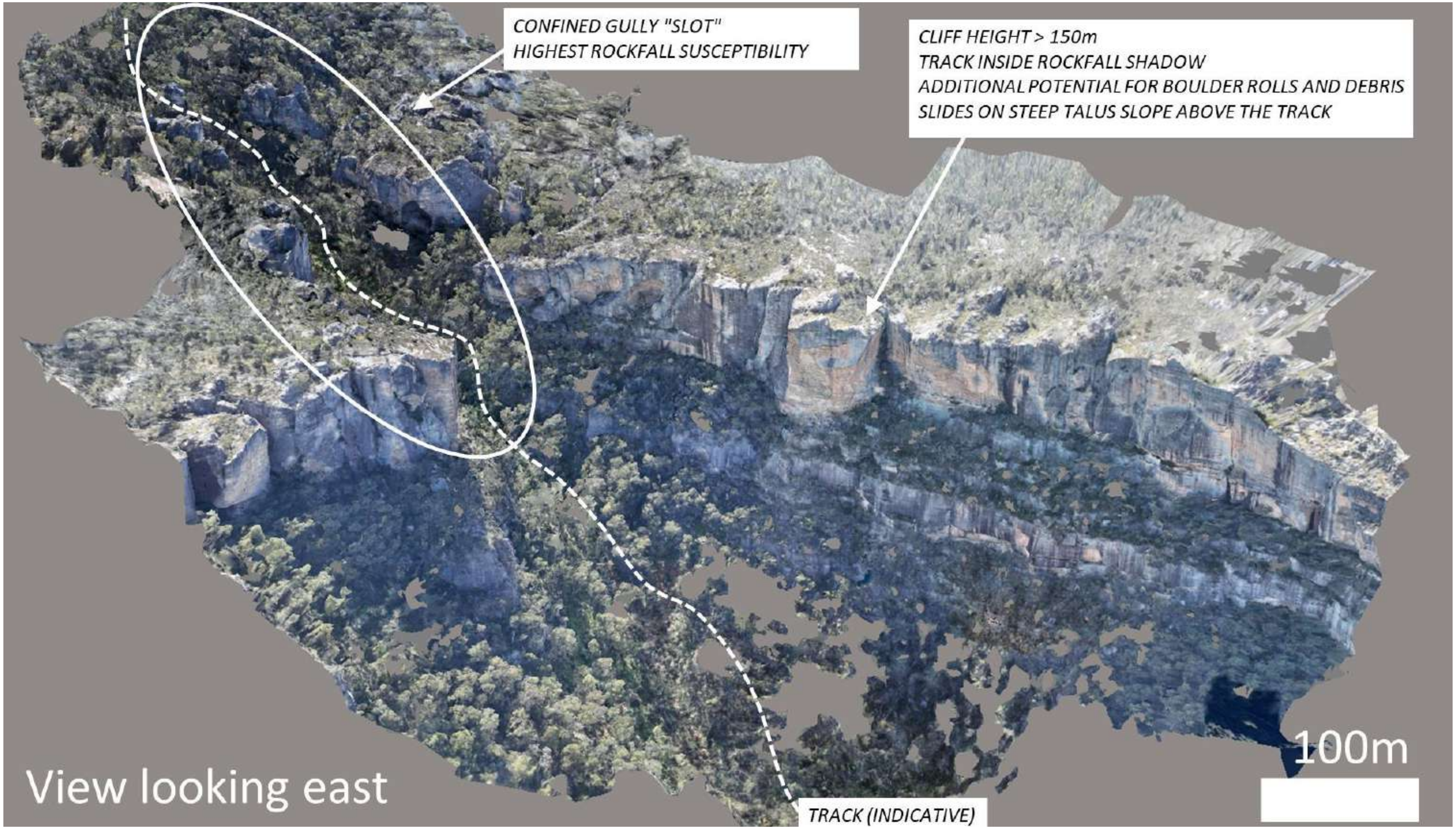

Figure 3-14: Annotated view of photogrammetry model of Section 3 (East)

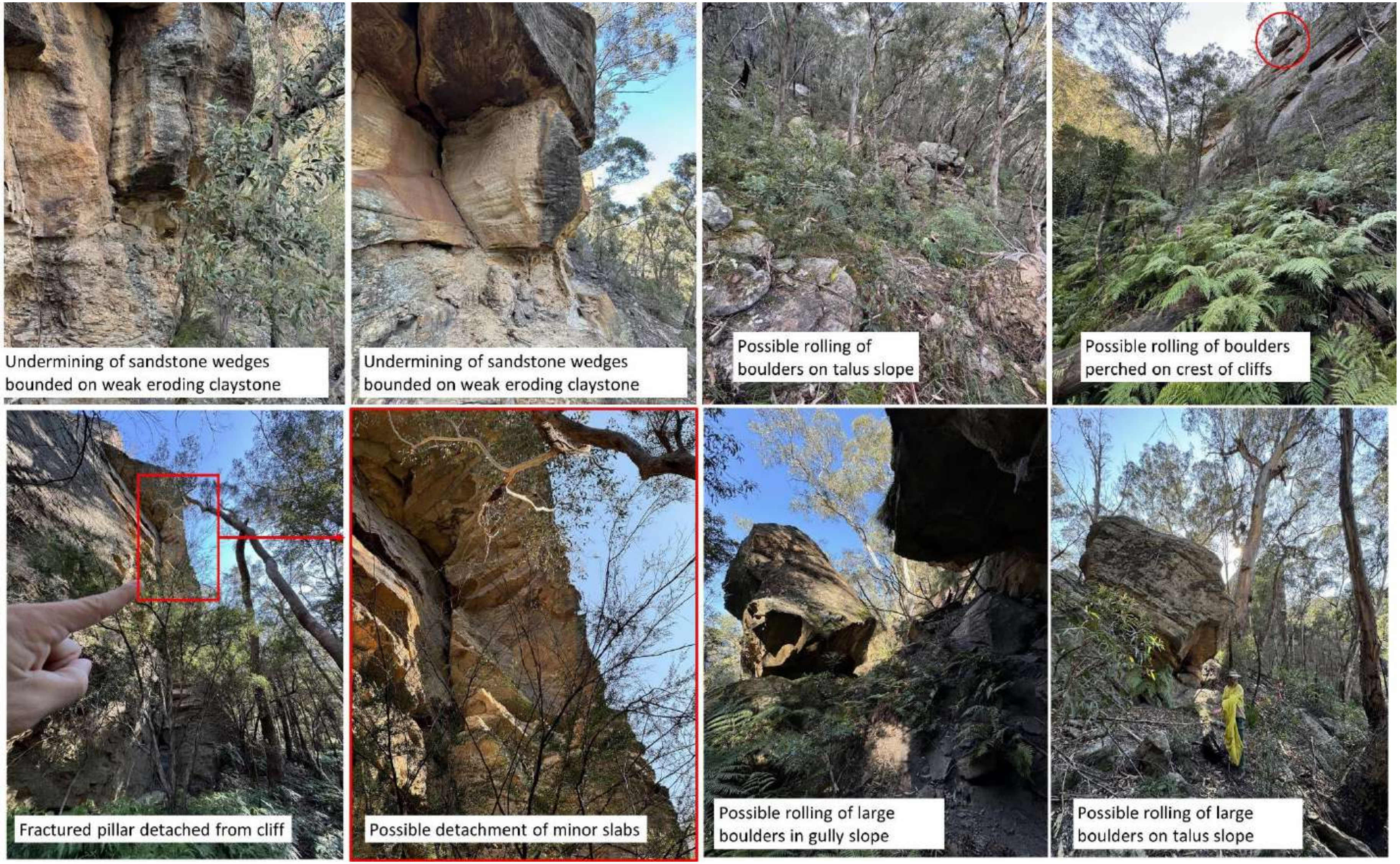

Figure 3-15: Trackside photographs of rockfall hazards in Section 3 (East)

4. GIS Landslide Susceptibility Mapping

4.1 GIS Methodology

Jacobs has used the publicly available DEM for the area to undertake a simplified landslide susceptibility assessment using two input parameters: (1) slope angle; and (2) horizon angle or "shadow angle" which represents the maximum angle between each cell in the digital elevation model, and the surrounding terrain.

- **Slope angle** influences landslide susceptibility because in broad terms, steeper slopes are expected to have lower Factor of Safety (FOS), and therefore higher potential for debris slides or other rotational and translational sliding failure mechanisms. Additionally, steeper slopes enable longer runout of rockfalls, which can bounce and roll further down a steep slope than a shallow slope.
- **Horizon angle** represents the location of a given grid cell in the terrain with respect to surrounding cliffs or steep slopes that rise above the site. Locations near the base of cliffs have maximum horizon angles approaching 90° and are associated with near certain probability of impact from rockfalls, because impact to the track only requires direct free-fall. Sections of track that are far from the base of the cliffs, or on gentle terrain, have lower shadow angles with decreased potential for rockfalls to runout and impact the track. Mapping the "rockfall shadow" of the escarpment is useful for understanding the reduction in risk that can be achieved by moving tracks or permanent assets (e.g. benches, look out points etc) away from the base of a cliff.

Figure 4-1 shows the proposed scoring rubric, where slope angle and horizon angle can each contribute a maximum of 50 points, for a maximum possible susceptibility score of 100, representing a "worst case" scenario with high likelihood of landslide (or rockfall) impact.

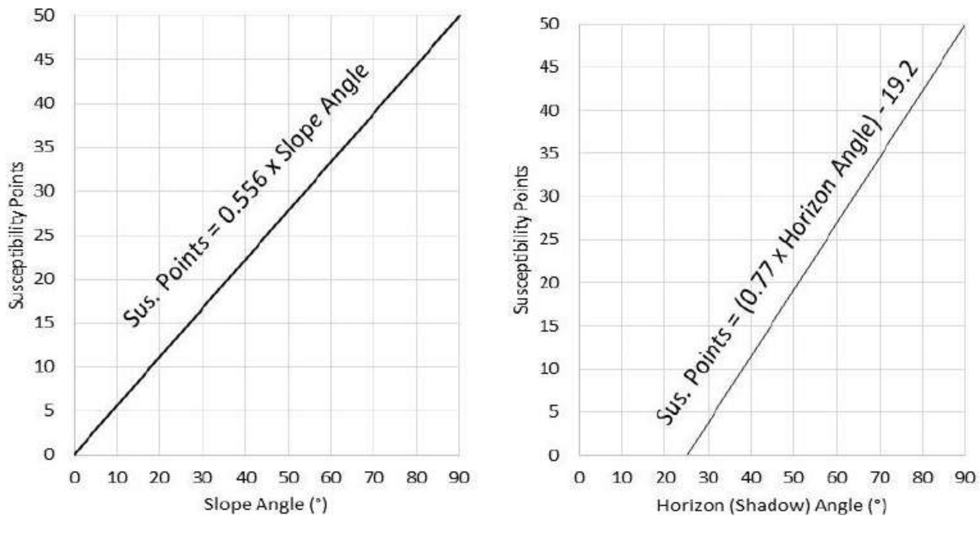

Figure 4-1: Scoring rubric for simplified landslide susceptibility based on slope and horizon angle

- The landslide susceptibility points contributed by slope angle scale linearly from 0 points for a flat slope of 0° up to 50 points for a vertical slope angle of 90°.
- The landslide susceptibility points contributed by horizon angle also scale from 0 to 50 points. A horizon of angle of 25° is assigned a score of 0 because few rockfalls are expected to involve long runout on shallow slopes where the minimum shadow angle is less than 25° (e.g. Jaboyedoff and Labiouse, 2011). The score scales linearly: a horizon angle of 90° indicates that the pixel is directly at the base of a vertical cliff, and so a maximum possible point score of 50 is assigned.

The next section presents a summary of the GIS mapping results, including a "heat map" of simplified landslide susceptibility, with the track segments classified into categories ranging from "low" to "very high".

4.2 GIS Mapping Results

Figure 4-2 shows the GIS map of slope angle across the entire project area. **Appendix B** contains supplementary maps including inset maps of localised areas at larger scale.

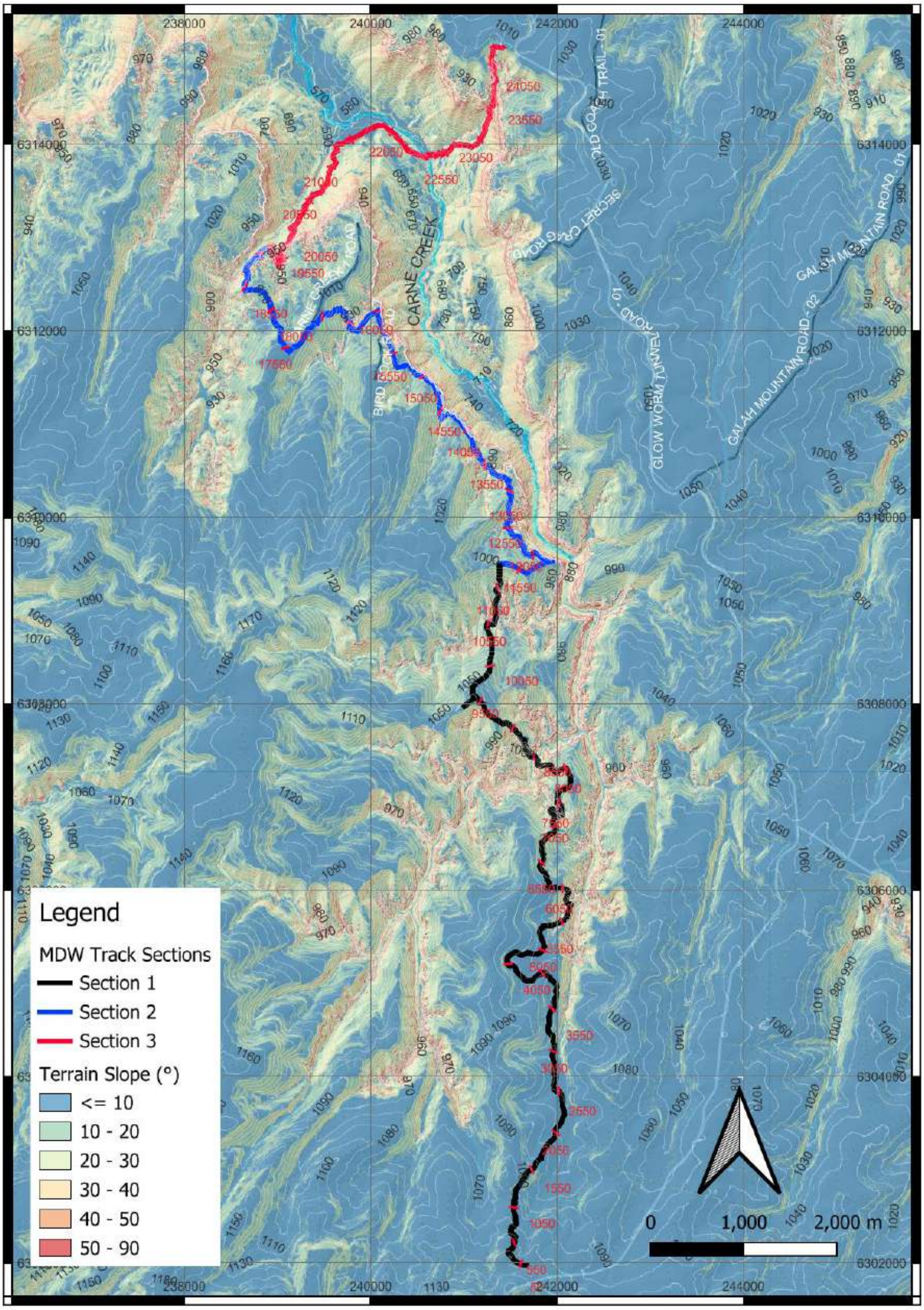

Figure 4-2: Global GIS map coloured by slope angle

Figure 4-3 shows the GIS map of horizon angle across the entire project area, clearly demonstrating how the eastern and western ends of Section 3 are the areas most susceptible to rockfall impact.

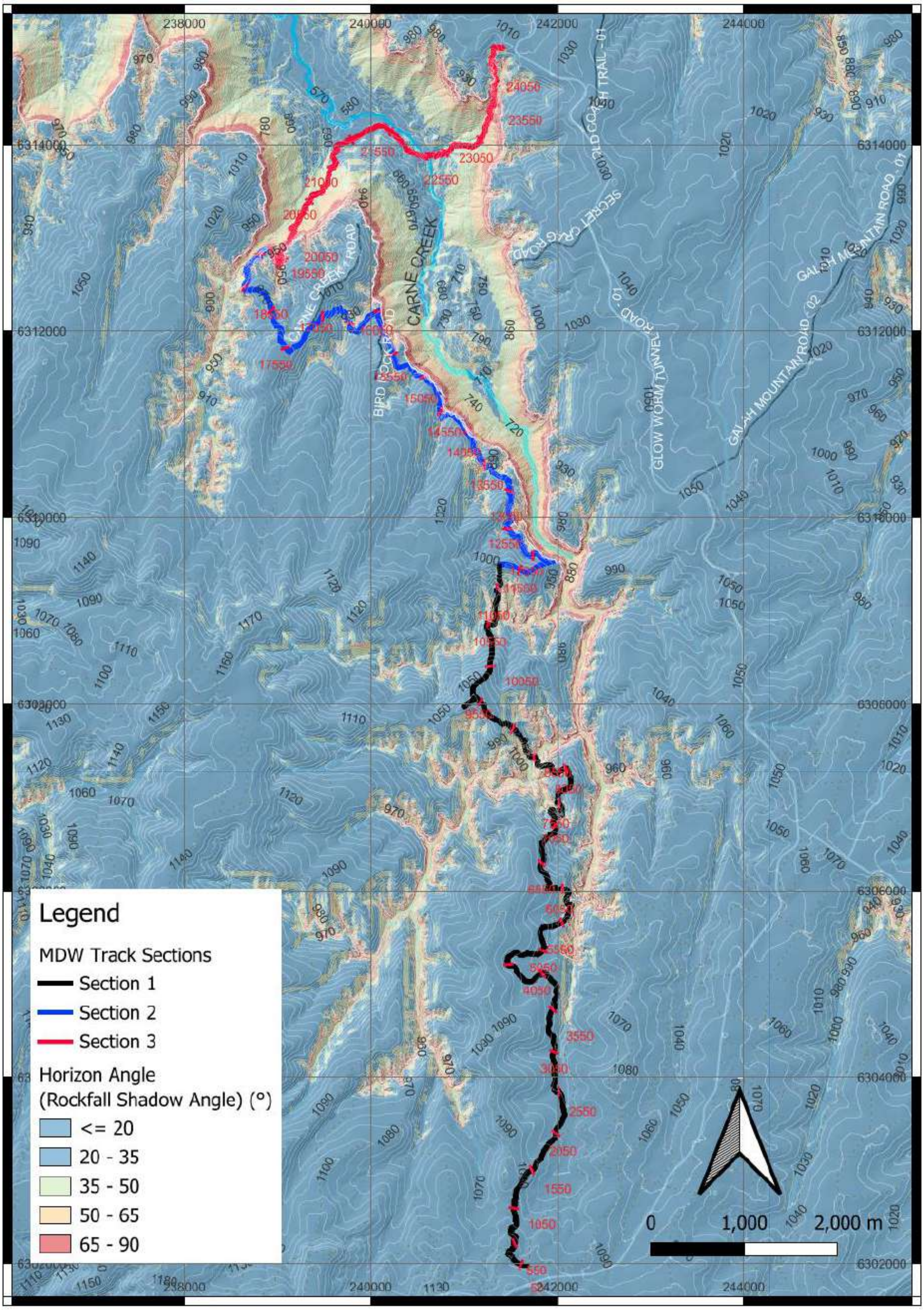

Figure 4-3: Global GIS map coloured by horizon angle

Figure 4-4 shows the resulting heat map of landslide susceptibility across the entire project area, with track segments divided into proposed landslide susceptibility categories based on the average terrain landslide susceptibility in a 20 m buffer region around the track. The areas of highest susceptibility are the eastern and western ends of Section 3.

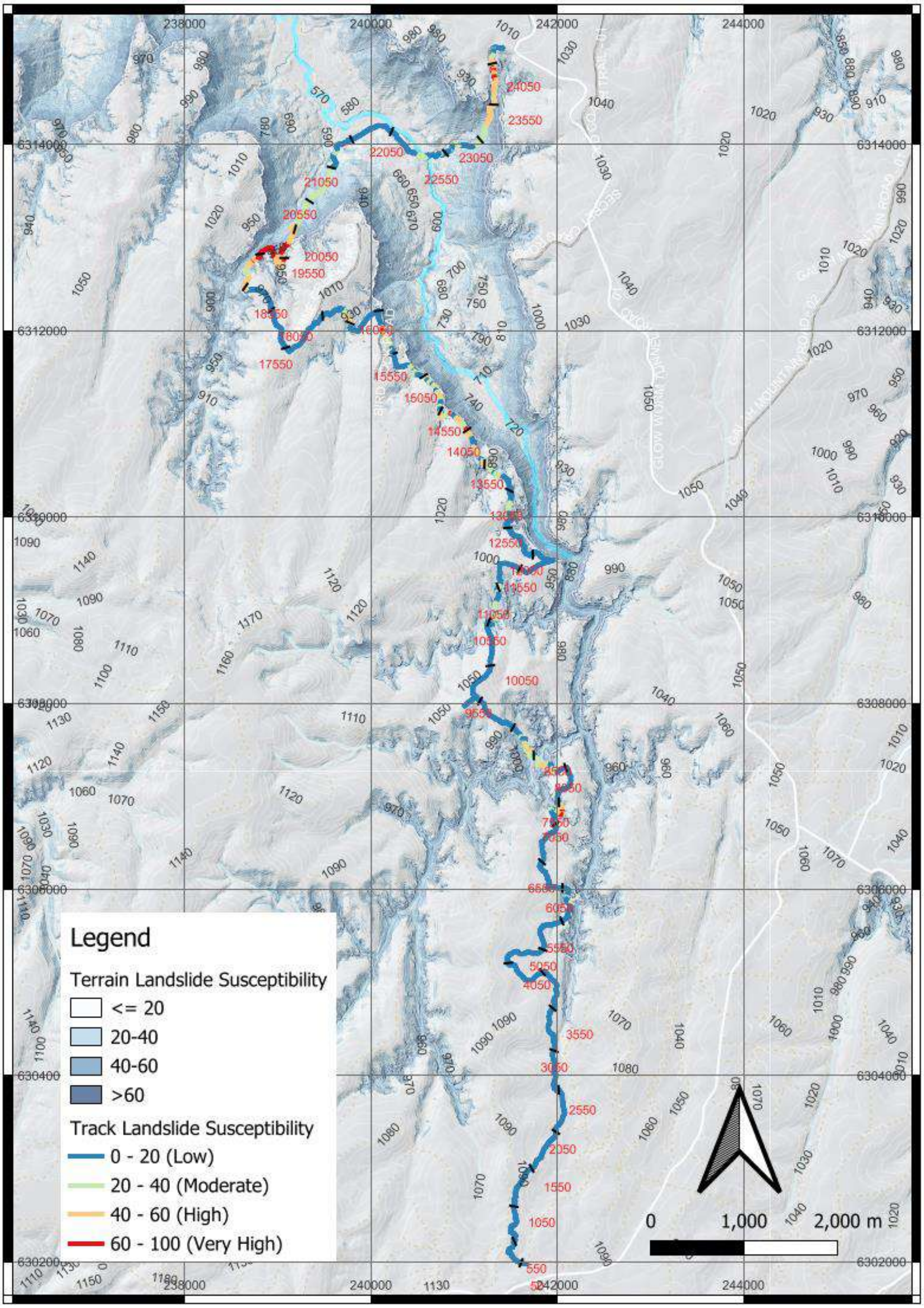

Figure 4-4: Global GIS map coloured by landslide susceptibility

Figure 4-5 presents the corresponding cumulative frequency curves of landslide susceptibility for each track section. The results clearly demonstrate how Section 3 is subject to the highest landslide susceptibility, with 32.6% of Section 3 being classified as either "high" or "very high" susceptibility.

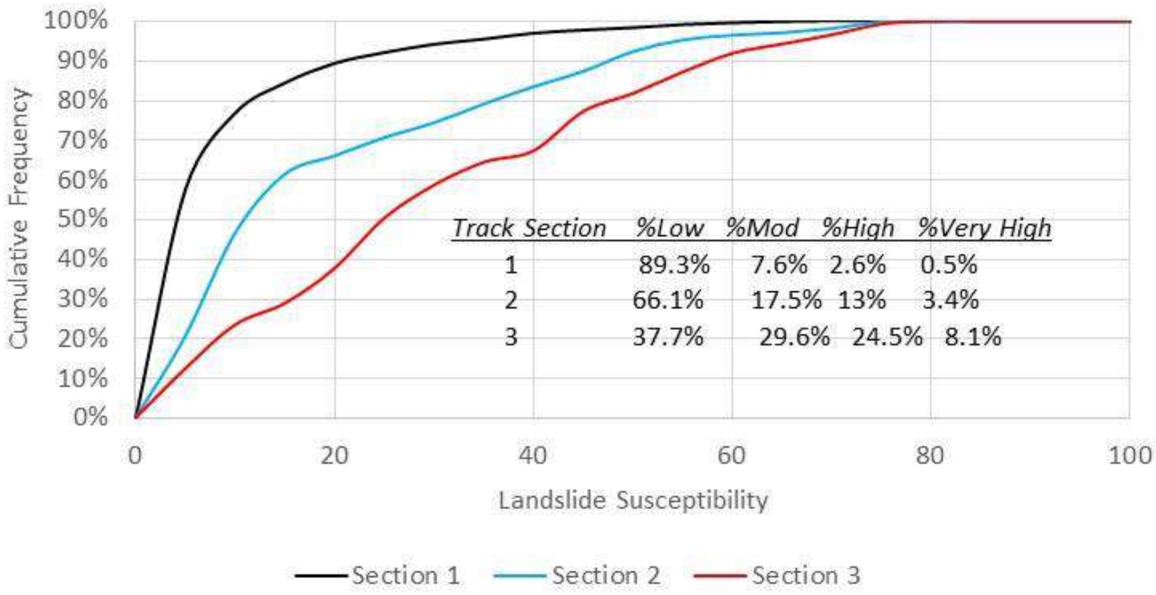

Figure 4-5: Cumulative frequency of track landslide susceptibility by section

The next section presents an analysis of the GIS results intended to provide preliminary guidance for the QRA parameters by linking the landslide susceptibility score to a synthetic estimate of landslide return period.

4.3 Synthetic Landslide Return Period from GIS

The QRA requires an estimate of annual probability of failure for each slope hazard. Although the GIS assessment of landslide susceptibility does not consider discrete, specific rock blocks or landslide mechanisms, the simplified landslide susceptibility score can be related to a synthetic (artificial) estimate of landslide return period for preliminary guidance. Jacobs proposes that an exponential relationship can be used for this purpose. These relationships are broadly applicable to many natural phenomena and have been shown to reflect empirical relationships between landslide magnitude-frequency and landslide volume-travel distance (e.g. Hungr et al., 1999). Figure 4-6 shows two example exponential relationships to estimate a "synthetic return period" (SRP) for landslide initiation based on the landslide susceptibility score.

Figure 4-6: Proposed relationships between landslide susceptibility and synthetic return period

Both relationships adopt a landslide return period of 10,000 years for a susceptibility score of zero. The baseline relationship assumes an upper bound (worst case) return period of 1 event per year (SRP = 1 year) for a susceptibility score of 100. The adverse relationship assumes an upper bound SRP of 0.1 years for a susceptibility score of 100, corresponding to an assumed frequency of 10 events per year.

Table 4-1 summarises selected SRP statistics under the baseline and adverse relationships for each track section on the multi-day walk.

Table 4-1: Selected SRP statistics per track section

SRP Statistics	Section 1		Section 2		Section 3	
	Baseline	**Adverse**	**Baseline**	**Adverse**	**Baseline**	**Adverse**
Minimum (years)	21	4	10	2	7	1
Median (years)	6943	6337	3685	2871	1041	592
90th % (years)	1422	873	128	43	49	13

It is important to emphasize that the SRP relationships are not directly calibrated to specific failure mechanisms (i.e. the SRP values are not specific to particular sizes or types of slope failure mechanisms such as "small rockfalls" or "large debris slides"). They are a *synthetic* desktop estimate of landslide likelihood based only on GIS data, and they are not a precise quantified estimate of probability of failure, nor a forecast of the date of future failure. The SRP data are intended for broad comparison purposes only, to give a preliminary indication of the plausible range of landslide frequency across the investigation area.

In broad terms the results provide a quantified basis to assert that Section 3 is subject to the highest landslide risk, and can be used for preliminary guidance on the potential range of landslide return periods. The minimum SRP of 1 year in Section 3 should be considered to correspond to the smallest scale of landslides, such as discrete rockfalls with source volumes nominally in the order of 1 m^3. The 90th percentile SRP (i.e. 10% of SRP values are more frequent) for Section 3 is approximately 13 years; this should be considered to correspond to larger slope failure events with total source volumes perhaps in the order of 10 m^3. The median (50th percentile) SRP for Section 3 is 592 years, and this should be expected to correspond to still larger landslide types with volumes exceeding nominally in the order of 100 m^3 to 1000 m^3.

The SRP values have been used along with the field investigation observations to inform the selection of the adopted QRA parameters, presented in the next section.

5. Quantitative Risk Assessment

5.1 Methodology

The Quantitative Risk Assessment (QRA) of slope hazards is based on the Australian Geomechanics Society (AGS) methodology (AGS 2007a,b,c) which has also been adopted in the NSW National Parks and Wildlife Service (NPWS) *Landslides and Rockfall Procedures* (2024, 2019). The annual risk of loss of life R_{LoL} for an at-risk individual (e.g. a walker on a track passing) is defined in as in Equation (1):

$$\boldsymbol{R_{LoL} = P_H \times P_{S:H} \times P_{T:S} \times V_{D:T}} \qquad \textbf{\textit{(1)}}$$

Where:

$P_H =$ *The annual probability that a landslide or rockfall occurs*

$P_{S:H} =$ *The probability that the landslide or rockfall reaches the track*

$P_{T:S} =$ *The probability that a person is present in the impact zone at the time of impact*

$V_{D:T} =$ *The probability of death of the individual if they are impacted*

The risk $\boldsymbol{R_{LoL}}$ is calculated for each discrete or generalised slope hazard in the site hazard inventory. Risk can be calculated for a single individual (i.e. a worker undertaking prescribed activities), or can be calculated for members of the public, by multiplying $\boldsymbol{R_{LoL}}$ by the total number of visitors to a walking track in a given year. Alternatively, the number of walkers can be incorporated into the $\boldsymbol{P_{T:S}}$ parameter, to estimate the proportion of time that walkers may be present in the nominal "impact zone" for a given hazard. The inverse of R_{LoL} represents the return period of fatality in years (one fatality in X years).

5.2 Risk Tolerability Criteria

This QRA considers life risk in terms of Societal Risk for public road users, and Individual Risk for workers undertaking construction activities, with the tolerability limits set out in the NPWS *Landslides and Rockfall Procedures* (2024), which are in turn adopted from ANCOLD (2003).

Societal risk represents the annualised risk to life to which society in general is exposed during daily life. For example, societal risk would include risk to a person driving a vehicle on a highway. Societal risk is different from voluntary risk, which could include high-risk activities like skydiving or mountain climbing.

Societal risk can be assessed against acceptability limits by plotting the *F* -*N* pairs for a geohazard, which represent the frequency of a fatality event *F* against the number of fatalities *N*, on a logarithmic scale. This investigation applies the 'expected value method' as described in AGS (2007c). The *F* values considers the frequency of rockfall or landslides impacting a track while people are present:

$$\boldsymbol{F = P_H \times P_{S:H} \times P_{T:S}} \qquad (2)$$

The 'N' value represents the weighted number of fatalities considering occupancy (i.e. the number of people in the exposed population e_s within the "impact zone" of landslide) and vulnerability $V_{D:T}$:

$$\boldsymbol{N = e_s \times V_{D:T}} \qquad (3)$$

The result is an F-N plot that represents the weighted number of expected fatalities for a given return period. For this assessment, weighted *N* values less than 1.0 have been rounded up to 1.0 for conservatism. Figure 5-1 presents the risk tolerability zones presented in the NPWS *Landslide and Rockfall Procedures*, which are adapted from ANCOLD (2003) and have been adopted for this study.

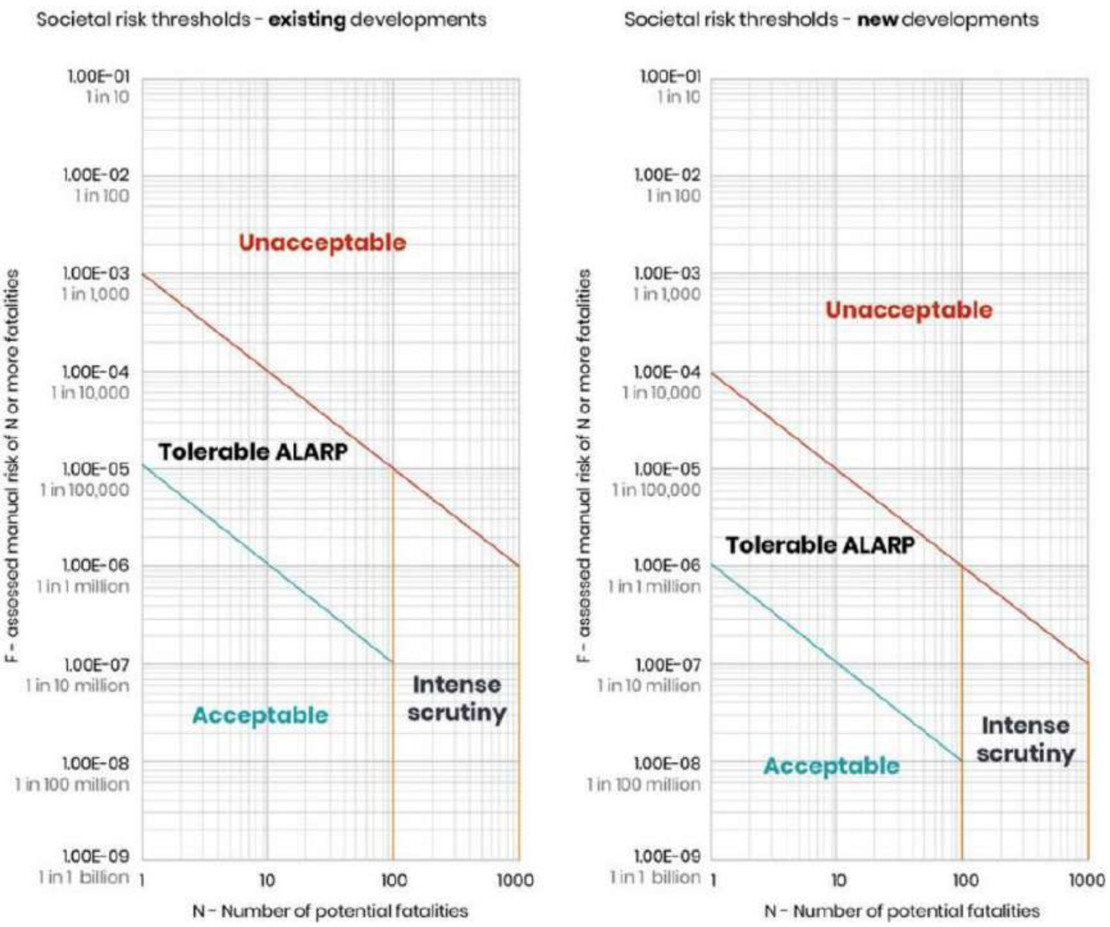

Figure 5-1: Societal risk tolerability F-N chart (from NPWS *Landslides and Rockfalls Procedures*)

Although the Gardens of Stone Multi-Day Walk is technically a "new development", it is being constructed in the natural environment of a national park, with an aim to minimise environmental impacts. Jacobs therefore recommends that the QRA should consider the site as an "existing development" for the purpose of landslide risk assessment. The boundary between Tolerable and Unacceptable risk, for an *N* = 1 fatality event, is one in 1000 years. Plotting the F-N pairs for each slope hazard requires estimating the exposed population e_s which represents the number of people that may be present in the "impact zone". The exposed population therefore depends on (1) the number and spacing of walkers present on the track at one time; and (2) the size of the slope failure.

For example: although a group of walkers may comprise, for example, a group of four people, these walkers are likely to be spaced out along the track, and therefore not all walkers may be within the impact zone of a rockfall or landslide at the same time. If a small rockfall only impacts a 1 m section of track, then only one person is likely to be present within that zone at the moment of impact. Section 5.3 summarises the full set of assumptions on exposed population and other parameters for each geohazard in the QRA.

Unlike Societal Risk, Individual Risk focuses on specific people exposed to a hazard, such as people living within the zone of impact of a potential landslide, or workers subject to landslide risk. The risk to life for individuals usually represents the additional increment of risk imposed by time and proximity to a hazard, and consensus is developing that risk to an individual from dam failure, for example, should not exceed the individual 'natural death' risk of the safest population group (10 to 14-year-old children).

The proposed limit of tolerability for individual risk as established by the United Kingdom Health and Safety Executive (UK HSE) and ANCOLD is 1 x 10^{-4} (1 fatality in 10,000 years) which is an order of magnitude less than the societal risk 'intolerable/unacceptable' criteria for an event with N = 1 fatality. This boundary may also be used to define the boundary between voluntary risk (i.e. restricted site access) and involuntary risk (general public access) (Nielsen et al., 1994) and has been adopted into the NPWS *Landslide and Rockfall Procedures*. Figure 5-2 shows how the individual risk limits for existing developments has been adapted to the F-N plot approach to assess individual risk for workers.

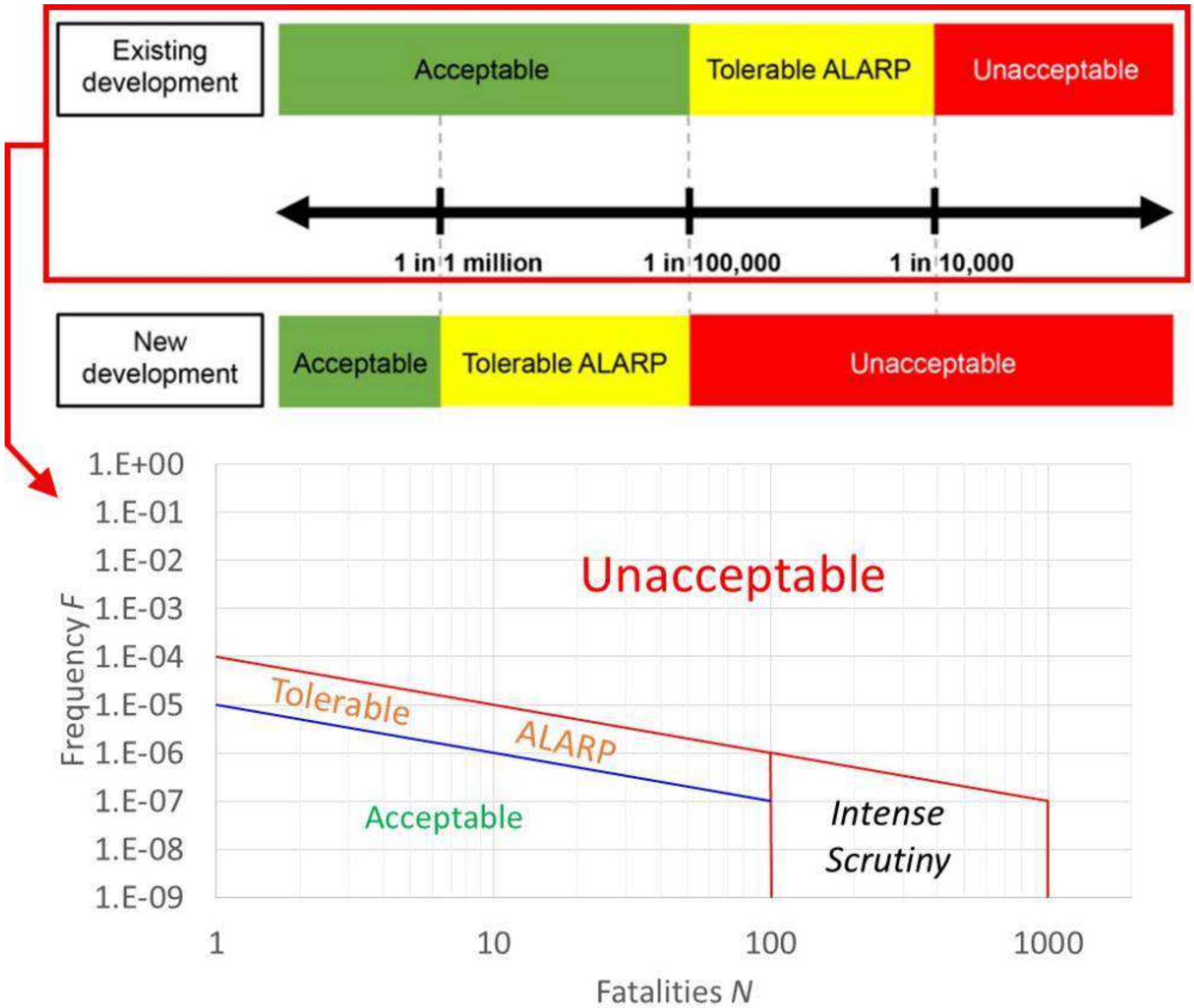

Figure 5-2 – Individual risk criteria for existing developments adapted to an F-N chart approach

These Individual Risk limits consider the boundary between "Unacceptable" and "Tolerable" risk for a single fatality event at 1 in 10,000 years, and the boundary between "Tolerable" and "Acceptable" at 1 in 100,000 years for existing developments.

5.3 QRA Inputs

5.3.1 QRA Extents

The QRA should be considered to encompass the extents of track sections inspected on foot. Generalised hazards consider the potential for rockfall or debris slides to occur anywhere in the project area, and therefore the QRA results for these hazards may also be extended to include any track sections rated as "moderate" or higher landslide susceptibility on the GIS maps. **Appendix B** contains supplementary GIS maps that show larger scale "heat maps" of landslide susceptibility for each track section.

5.3.2 Hazard Inventory and Assumed Return Periods

The first step in the QRA begins with the development of the slope hazard inventory, considering all relevant slope hazards that may pose a risk to life. The identification of hazards is part of the geotechnical characterisation of the site; the expected slope instability mechanisms depend on the dominant lithology, rock structure (discontinuities), and topography.

The site inspection observations have been used to develop expected slope hazard types and size categories. The primary slope hazards for the site involve (1) rockfalls and (2) debris slides. Both of these hazard types are expected to vary in scale across several orders of magnitude. While Jacobs has highlighted a limited selection of discrete, specific detached rock blocks and other slope hazards, it is not feasible to identify every potential rockfall block or debris slide location. Therefore, Jacobs has developed the QRA primarily considering a variety of generalised slope hazards, representing our estimation of a credible range of potential slope failure sizes, and their associated return periods. Each hazard type refers to a range of potential failure sizes, with associated variation in typical source volume, block edge dimensions, composition (single discrete rockfall blocks, versus larger failures that may involve a cluster of several blocks or a rock mass scale collapse), recurrence frequency, and probability of fatality if walkers are impacted.

Figure 5-3 shows a conceptual illustration of rockfall size categories varying across five orders of magnitude, with corresponding variation in composition, frequency, and vulnerability. Hazard scale varies from small rockfalls that may occur several times per year, up to large events with indicative return periods in the hundreds to thousands of years for a given site.

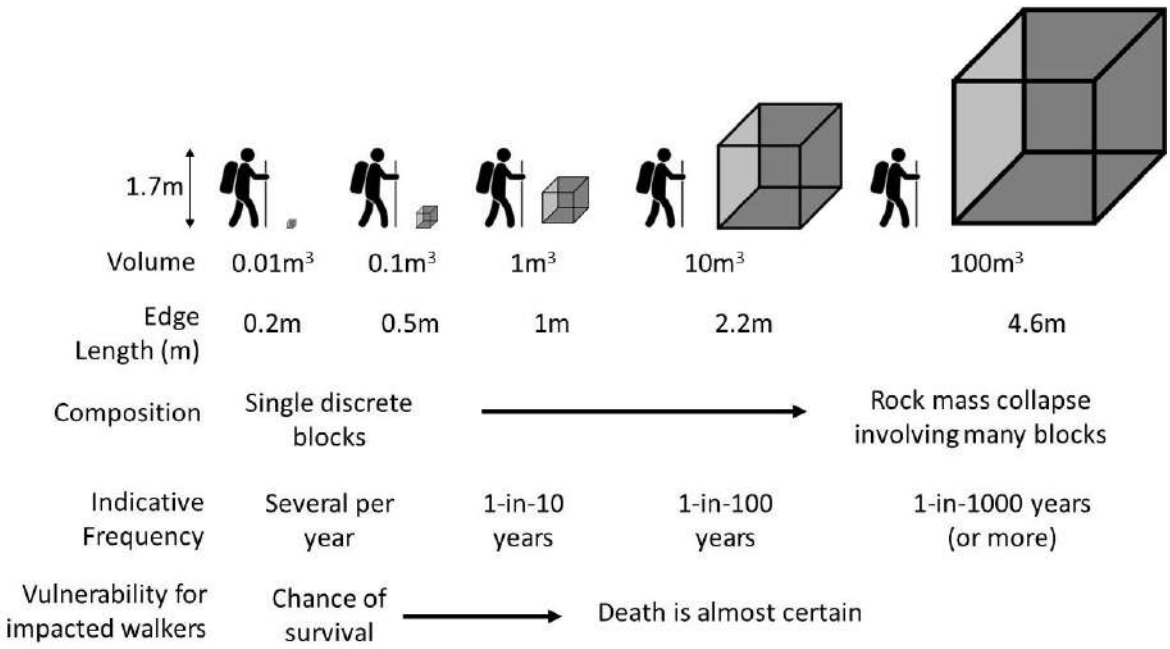

Figure 5-3: Conceptual illustration of potential rockfall sizes across four orders of magnitude

This QRA considers a hazard inventory reflecting a wide range of potential landslide sizes, with associated variation in typical source volume, block dimensions, and composition (i.e. single discrete rockfall blocks, versus larger failures that may involve a cluster of several blocks or a rock mass scale collapse). Annualised probability of failure P_H has been estimated for each hazard based on a synthesis of the field observations and interpretation of the GIS landslide susceptibility mapping.

The hazard inventory for this QRA considers two categories of landslides, including (1) rockfalls initiating from the escarpment cliffs; and (2) debris slides initiating on the talus slope. Table 5-1 summarises the QRA hazard inventory, including descriptors of landslide size, the indicative range of landslide source volume, and the typical block edge length for rockfalls, or width, runout length, and depth of debris slides.

Table 5-1: Summary of slope hazard inventory

Hazard ID	Type	Description	Total Source Volume (m^3)	Typical Block Edge Length (m) or Indicative Slide Dimensions (W x L x Depth)
H1.1	Rockfalls from cliffs	Very small	< 0.01	0.2
H1.2		Small	0.01 to 0.1	0.5
H1.3		Medium	0.1 to 1.0	0.7
H1.4		Large	1.0 to 10	0.8 (several blocks)
H1.5		Very large	10 to 100	1.0 (many blocks)
H1.6		Rock mass collapse	> 100	1.0 (many blocks and debris)
H2.1	Debris slides on talus slope	Very small	< 100	10m x 4m x 1m
H2.2		Small	100 to 1000	10m x 5m x 1.5m
H2.3		Medium	1000 to 10,000	20m x 30m x 2m
H2.4		Large	10,000 to 100,000	60m x 90m x 6m
H2.5		Very large	>100,000	100m x 200m x 10m

At a regional scale, landslides and rockfalls typically follow a negative-exponential or lognormal magnitude-frequency relationship. The result is intuitive: smaller rockfalls and slides are exponentially more frequent that larger events. On a logarithmic scale plot, the cumulative frequency relationship is a straight line with a negative slope. Using natural scale, the magnitude-frequency relationship tends to fit a negative exponential curve. Figure 5-4 shows examples of site-specific rockfall magnitude-frequency relationships developed for a section of highway in British Columbia, Canada using years of rockfall records.

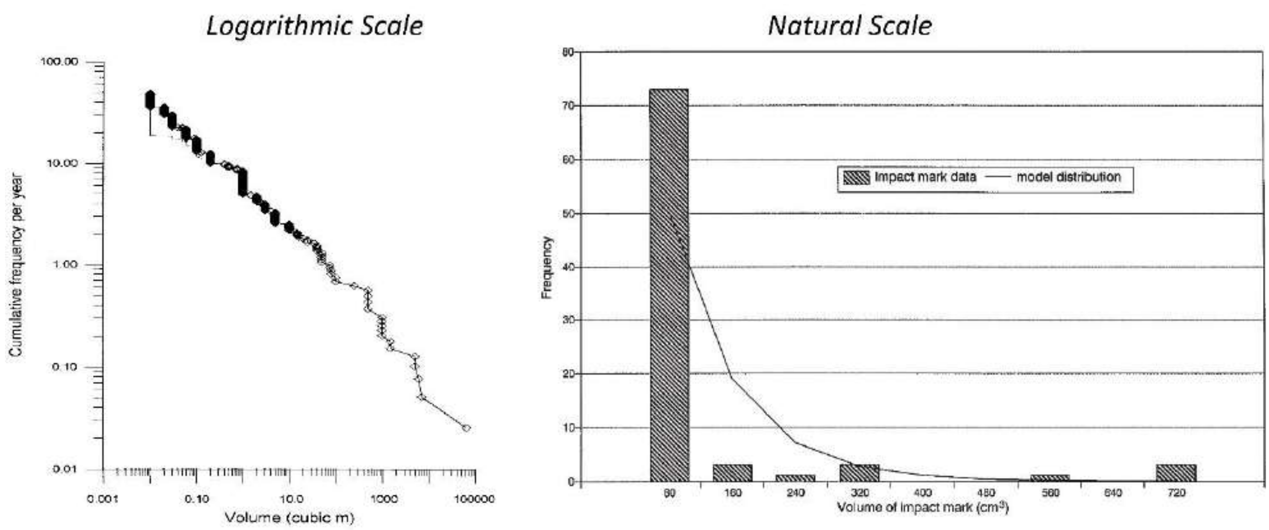

Figure 5-4: Examples of empirical magnitude-frequency relationships for rockfalls

Source: Bunce et al. (1997) and Hungr et al. (1999)

If extensive records of past failures are available, the QRA landslide frequency P_H parameter can be estimated based on the frequency of historical failures at a given site, to develop a magnitude frequency relationship similar to the curves shown above in Figure 5-4. If no records are available or if the potential mechanism represents a large-scale, very long return period event, then semi-quantitative guidelines can be used to estimate the return period. This QRA adopts P_H parameters based on our geological assessment of the site, observations from the track inspections, and review of the GIS landslide susceptibility mapping data.

In the absence of site-specific slope monitoring data, it is important to emphasize that any estimate of probability of failure or landslide return period represents a probabilistic appraisal based on engineering judgement and, if available, local empirical records of past slope instability and site observations. The adopted return period is intended represent long-term averages over geological time scales; they do not represent a precise forecast of the date of failure. For example, a 1 in 100-year probability of rockfall does not mean that no rockfalls will occur for 100 years. Such an event could occur tomorrow, or twice within a short time, especially if triggered by adverse circumstances such as unpredictable earthquakes, intense or prolonged wet weather (such as those associated with La Niña weather conditions).

Table 5-4 summarises the adopted annual return period values used to calculate P_H for each hazard and track geotechnical domain. Note that not all hazard categories are expected to occur in every domain; in particular, the topographic conditions of track Section 1 are unexpected to produce potential for “large” and “very large” debris slides based on the limited slope heights above these sections of track, which generally traverse gentle terrain across the top of the escarpment plateau. For Section 2, these “large” and “very large” debris slides also include the potential for deep-seated failures comparable to the ancient Carne Creek landslide, which could involve loss of track sections that follow the crest of the cliff.

Table 5-2: Summary of adopted slope hazard return periods used to estimated P_H

Hazard ID	Type	Size	Return Period (Years) Per Track Section 1	2	3
H1.1	Rockfalls from cliffs	Very small	10	5	1
H1.2		Small	20	10	2
H1.3		Medium	60	20	5
H1.4		Large	200	100	10
H1.5		Very large	1000	500	60
H1.6		Rock mass collapse	5000	1000*	200*
H2.1	Debris slides on talus slope	Very small	50	20	5
H2.2		Small	100	60	20
H2.3		Medium	1000	1000*	200
H2.4		Large	n/a	2000*	2000
H2.5		Very large (i.e. Comparable to ancient Carne Creek slide)	n/a	10,000*	10,000

**Typically expected to involve cliff collapse events.*

5.3.3 Spatial Probability of Impact

Not all rockfalls or debris slides will necessarily reach the track. The probability of impact $P_{S:H}$ depends on the size of the rock fall or landslide, the distance and gradient of the slope between the source zone and the site, and the slope surface characteristics, including vegetation cover type and density. Larger slides and rockfalls will tend to travel greater distances, and steeper slopes allow for longer runout. Trees and other vegetation can absorb energy and decrease travel distance.

The $P_{S:H}$ factor also considers the ability of persons to avoid impact with the failure (i.e. people may be able to flee the area before impact if failure moves sufficiently slowly, or if it originates far away). The adopted $P_{S:H}$ parameters in this QRA consider the landslide size and the location of the track with respect to the “rockfall shadow” of the escarpment cliffs, as quantified in the simplified GIS landslide susceptibility assessment.

Broadly speaking, larger debris slides and rockfalls have a higher probability of longer runout, and therefore a higher probability of spatial impact. Sections of track that pass directly under the steep cliffs that form the primary source zone are expected to have probability of spatial impact approaching 100% (i.e. the highest risk parts of Section 3 and the western and eastern routes into the Wolgan Valley.

Table 5-3 summarises the $P_{S:H}$ parameters adopted for each hazard and track section.

Table 5-3: Summary of adopted probability of spatial impact $P_{S:H}$

Hazard ID	Type	Size	Probability of Spatial Impact $P_{S:H}$ 1	2	3
H1.1	Rockfalls from cliffs	Very small	0.1	0.1	0.2
H1.2		Small	0.2	0.2	0.5
H1.3		Medium	0.4	0.4	0.8
H1.4		Large	0.6	0.6	1.0
H1.5		Very large	1.0	1.0	1.0
H1.6		Rock mass collapse	1.0	1.0	1.0
H2.1	Debris slides on talus slope	Very small	0.2	0.2	0.4
H2.2		Small	0.4	0.4	0.8
H2.3		Medium	0.8	0.8	1.0
H2.4		Large	n/a	1.0	1.0
H2.5		Very large (i.e. Comparable to ancient Carne Creek slide)	n/a	1.0	1.0

The next section describes the temporal assumptions for visitors and track workers.

5.3.4 Temporal Probability of Impact

The temporal exposure parameter $P_{T:S}$ has been scaled depending on the size of the landslide "impact zone". Small rockfalls impacting, for instance, a 1 m section of track, will involve a much lower temporal exposure than large cliff collapse that impact hundreds of metres of track. The size of the impact zone also affects the number of people present: a small rockfall will only have the potential to impact one person; larger failures impact a wider section of track. For the societal risk assessment, the QRA has considered two visitation scenarios based on site usage projections provided by NPWS, with (1) initial visitation of 30,000 walkers per year; and (2) long-term visitation rising to 60,000 visitors per year.

Visitors are assumed to walk in pairs, at a speed of 3 km/h. Table 5-4 summarises the resulting estimates of total annual "exposure hours" when people are present in the "impact zone" of each hazard type.

Table 5-4: Summary of slope hazard temporal parameters

Hazard ID	Type	Impacted Track Length	Assumed Impact Zone Width (m)	Impacted Population e_s	Annual Exposure Hours 30,000 Visitors/year	60,000 Visitors/year
H1.1	Rockfalls from cliffs	Very small	1	1	10	20
H1.2		Small	3	1	30	60
H1.3		Medium	5	2	50	100
H1.4		Large	10	2	100	200
H1.5		Very large	20	2	200	400
H1.6		Rock mass collapse	40	2	400	800
H2.1	Debris slides on talus slope	Very small	10	2	100	200
H2.2		Small	15	2	150	300
H2.3		Medium	30	2	300	600
H2.4		Large	60	2	600	1200
H2.5		Very large	90	2	900	1800

In calculating the individual risk for track construction workers, Jacobs has estimated temporal exposure using an assumed rate of construction progress in terms of completed track metres per day, with estimated rates provided by NPWS. The track length in each section has been sub-sampled so that only the relevant areas that are subject to the highest rockfall and landslide risk are included; areas traversing the gentle terrain along the top of the escarpment are excluded (Figure 5-5).

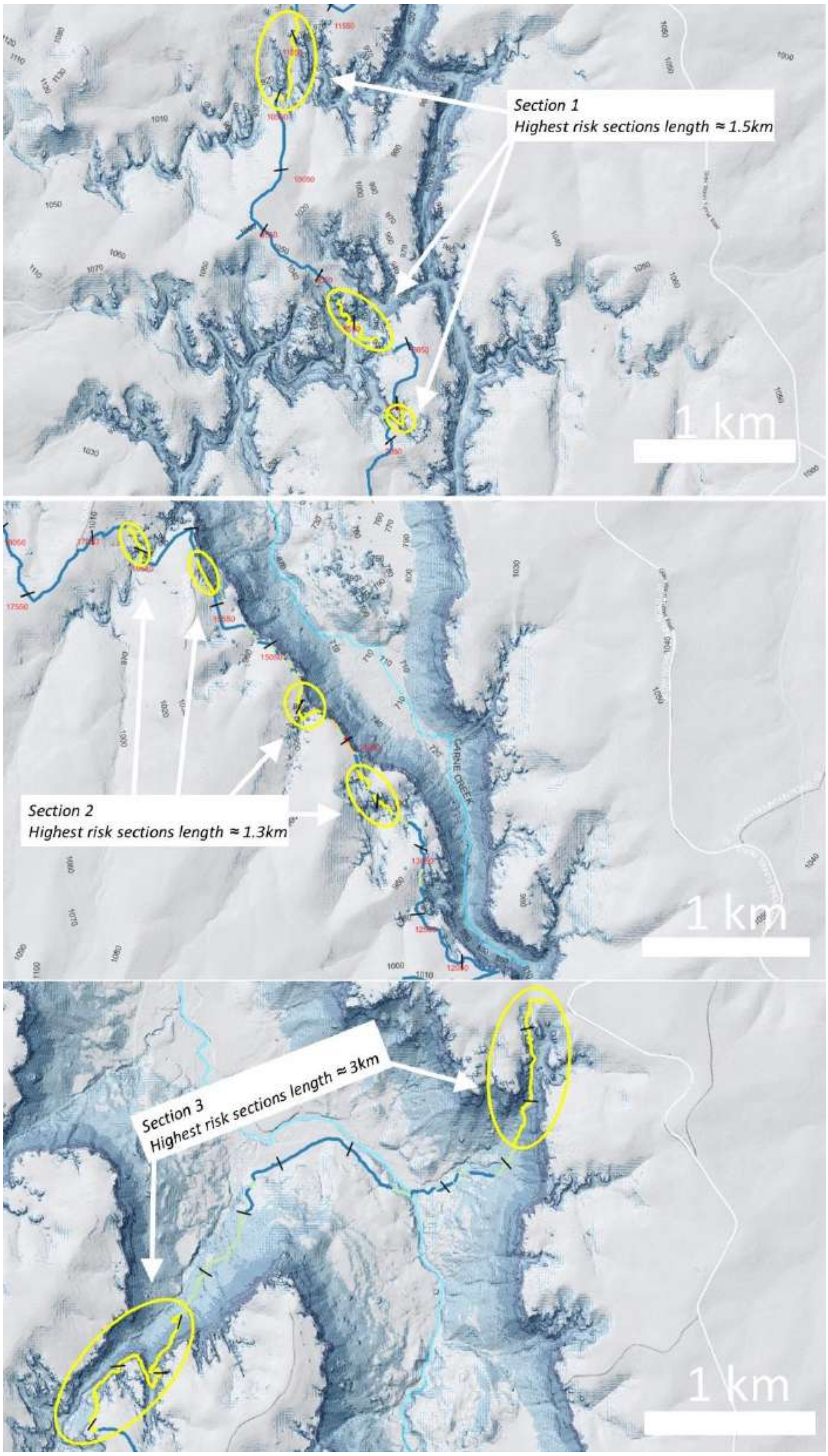

Figure 5-5: Delineation of highest landslide risk zones for workers

For Section 2 NPWS estimated worker time of 868 "person days" over a 6.5 km length of track, for an average rate of 7.5 m/day. For the steepest sections of Section 3 (east and west approaches into the Wolgan Valley), the rate has been reduced to 5 m/day based on the expectation of slower construction in difficult terrain. Table 5-6 summarises the resulting estimate of total person days and program days, considering the length of "at-risk" track in each section, the construction progress rate.

Table 5-5: Summary of slope hazard temporal parameters

Track Section	Total Length (m)	Highest Risk Length (m)	Metres Per Person-Day	Person Days	Program Days*
Section 1	11,500	1500	7.5	200	100
Section 2	8,200	1300	7.5	173	87
Section 3	5,500	3000	5.0	600	300

**Program days consider that the work is completed by a 2-person team.*

The program days represent the total time that workers are present within the at-risk sections of track, on the assumption that work will be completed, on average, by a two-person team. The total program days in each section have been used to estimate the total time workers will spend in the notional "impact zone" of each landslide hazard, scaled according to the size of each hazard's "impact zone".

Table 5-6 summarises the total time workers are expected to be present in the impact zone of each hazard type, in each track section.

Table 5-6: Summary of slope hazard temporal parameters

Hazard ID	Type	Impacted Track Length	Assumed Impact Zone Width (m)	Impacted Population e_s	Total Exposure Hours Section 1	Section 2	Section 3
H1.1	Rockfalls from cliffs	Very small	1	1	1.6	1.6	2.4
H1.2		Small	3	1	4.8	4.8	7.2
H1.3		Medium	5	2	8.0	8.0	12.0
H1.4		Large	10	2	16.0	16.1	24.0
H1.5		Very large	20	2	32.0	32.1	48.0
H1.6		Rock mass collapse	40	2	64.0	64.2	96.0
H2.1	Debris slides on talus slope	Very small	10	2	16.0	16.1	24.0
H2.2		Small	15	2	24.0	24.1	36.0
H2.3		Medium	30	2	48.0	48.2	72.0
H2.4		Large	60	2	n/a	96.4	144.0
H2.5		Very large	90	2	n/a	144.6	216.0

The $P_{T:S}$ parameter also includes a 50% reduction factor to account for the potential that slope failure may occur at night, whereas people are only expected to be present during daylight hours. A further 50% reduction factor is applied to account for the effective implementation of an administrative slope risk management plan, including (1) annual track inspections with closures after observed landslides; (2) landslide warning signage; and (3) rainfall-based track closures in accordance with the local area TARP. The resulting QRA risk calculations therefore consider the **residual risk** at the site assuming the slope risk management regime is implemented.

5.4 Vulnerability

Vulnerability represents an empirical estimation of the likelihood of death or injury of persons impacted by a rock fall or landslide. The parameter depends on the size and speed of a landslide or rock fall, whether the person is in the open or protected by a vehicle or a building, and whether the vehicle or building is damaged or collapses from the impact. Table 5-7 presents a selection of reference vulnerability values for rock fall and landslide impacts to people in open space or in a vehicle.

Table 5-7: Example of suggested vulnerability ratings for rock fall and landslides (AGS, 2007)

Failure Type		Typical Vulnerability Rating	Outcome
Person in open space	If struck by rock fall	0.1 to 0.7	Dependent on rock fall size
	If buried by debris slide	0.8 to 1.0	Significant trauma, terminal injury, death by asphyxia almost certain
	If struck by debris slide but not buried	0.1 to 0.5	Significant trauma, terminal injury, possibility of survival
Person in a vehicle	If the vehicle is buried/crushed	0.9 to 1.0	Death is almost certain
	If the vehicle is damaged only	0 to 0.3	High chance of survival

Table 5-8 summarises the adopted vulnerability parameters; they are held constant across each track section.

Table 5-8: Summary of slope hazard vulnerability parameters

Hazard ID	Type	Description	Total Source Volume (m^3)	Vulnerability $V_{D:T}$
H1.1	Rockfalls from cliffs	Very small	< 0.01	0.1
H1.2		Small	0.01 to 0.1	0.2
H1.3		Medium	0.1 to 1.0	0.5
H1.4		Large	1.0 to 10	0.9
H1.5		Very large	10 to 100	1.0
H1.6		Rock mass collapse	> 100	1.0
H2.1	Debris slides on talus slope	Very small	< 100	0.3
H2.2		Small	100 to 1000	0.6
H2.3		Medium	1000 to 10,000	0.9
H2.4		Large	10,000 to 100,000	1.0
H2.5		Very large	>100,000	1.0

The next section summarises the QRA results.

5.5 QRA Results

5.5.1 Societal Risk for Walkers

Table 5-9 summarises the results of the societal risk QRA for 30,000 walkers per year. The results represent the **residual risk** at the site, accounting for a reduction factor based on the effective implementation of a Trigger Action Response Plan (TARP) that specifies wet weather track closures in accordance with previous advice from Jacobs (2023), regular inspection of the track by NPWS staff, and track closures following the observation of new rockfall or debris slide impacts.

Table 5-9: Summary of societal risk results for 30,000 walkers per year

Hazard ID	Type	Size	Societal Risk Class		
			Section 1	Section 2	Section 3
H1.1	Rockfalls from cliffs	Very small	Acceptable	Acceptable	Tolerable
H1.2		Small	Acceptable	Tolerable	Tolerable
H1.3		Medium	Acceptable	Tolerable	Tolerable
H1.4		Large	Tolerable	Tolerable	Tolerable
H1.5		Very large	Tolerable	Tolerable	Tolerable
H1.6		Rock mass collapse	Acceptable	Tolerable	Tolerable
H2.1	Debris slides on talus slope	Very small	Tolerable	Tolerable	Tolerable
H2.2		Small	Tolerable	Tolerable	Tolerable
H2.3		Medium	Tolerable	Tolerable	Tolerable
H2.4		Large	n/a	Tolerable	Tolerable
H2.5		Very large (i.e. Comparable to ancient Carne Creek slide)	n/a	Acceptable	Acceptable

All of the hazards are expected to represent either a *Tolerable* or *Acceptable* increment of societal and individual risk. Table 5-10 shows the societal risk classifications under a long-term increased visitation scenario of 60,000 visitors per year.

Table 5-10: Summary of societal risk results for 60,000 walkers per year

Hazard ID	Type	Size	Return Period (Years) Per Track Section		
			1	2	3
H1.1	Rockfalls from cliffs	Very small	Acceptable	Tolerable	Tolerable
H1.2		Small	Tolerable	Tolerable	Tolerable
H1.3		Medium	Tolerable	Tolerable	Tolerable
H1.4		Large	Tolerable	Tolerable	Unacceptable
H1.5		Very large	Tolerable	Tolerable	Tolerable
H1.6		Rock mass collapse	Acceptable	Tolerable	Tolerable
H2.1	Debris slides on talus slope	Very small	Tolerable	Tolerable	Tolerable
H2.2		Small	Tolerable	Tolerable	Tolerable
H2.3		Medium	Tolerable	Tolerable	Tolerable
H2.4		Large	n/a	Tolerable	Tolerable
H2.5		Very large (i.e. Comparable to ancient Carne Creek slide)	n/a	Tolerable	Tolerable

The results show that the only hazard estimated to be unacceptable is large rockfalls (H1.4) occurring in Section 3 under the long-term increased visitation scenario.

Figure 5-6 presents the corresponding F-N plots for the 30,000 visitors per year scenario; Figure 5-7 presents the F-N plots for the long-term high visitation scenario with 60,000 visitors per year.

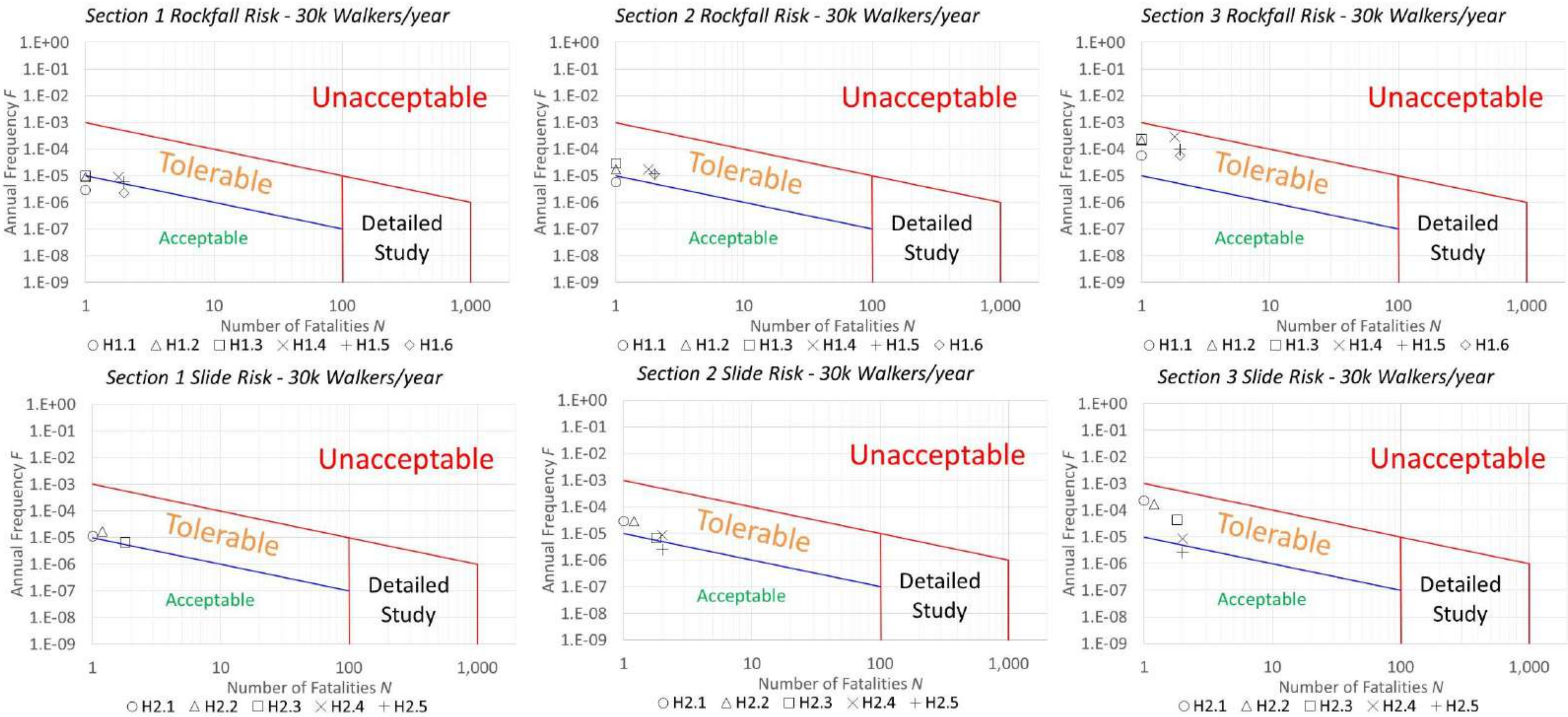

Figure 5-6: **F-N plot of societal risk for 30,00 visitors per year**

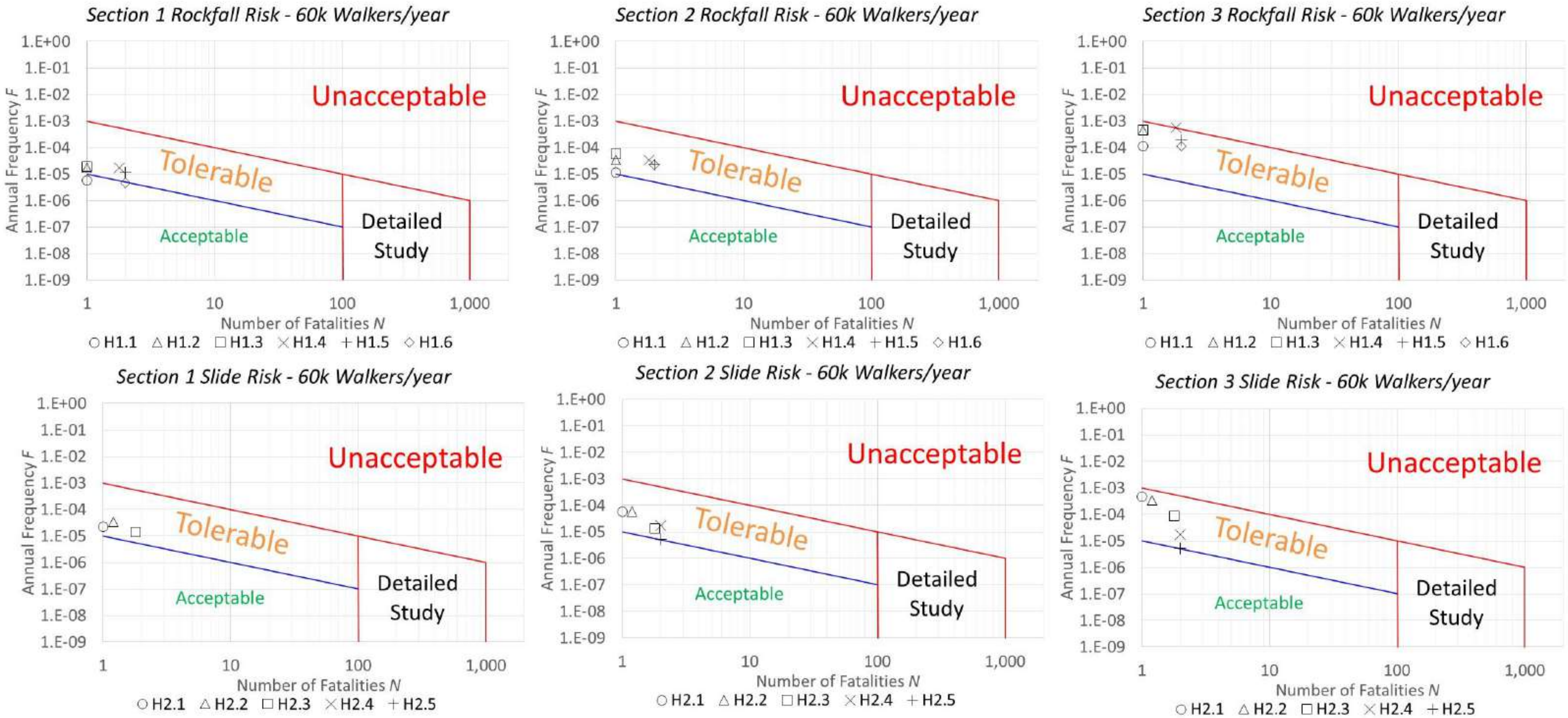

Figure 5-7: **F-N plot of societal risk for 60,00 visitors per year**

5.5.2 Individual Risk for Workers

Table 5-9 summarises the results of the individual risk QRA for workers. The results represent the **residual risk** at the site, accounting for a reduction factor based on the effective implementation of a Trigger Action Response Plan (TARP) that specifies wet weather track closures in accordance with previous advice from Jacobs (2023), regular inspection of the track by NPWS staff, and track closures following the observation of new rockfall or debris slide impacts.

Table 5-11: Summary of individual risk for workers

Hazard ID	Type	Size	Societal Risk Class		
			Section 1	Section 2	Section 3
H1.1	Rockfalls from cliffs	Very small	Acceptable	Acceptable	Tolerable
H1.2		Small	Acceptable	Acceptable	Tolerable
H1.3		Medium	Acceptable	Acceptable	Tolerable
H1.4		Large	Acceptable	Acceptable	Unacceptable
H1.5		Very large	Acceptable	Acceptable	Tolerable
H1.6		Rock mass collapse	Acceptable	Acceptable	Tolerable
H2.1	Debris slides on talus slope	Very small	Acceptable	Acceptable	Tolerable
H2.2		Small	Acceptable	Acceptable	Tolerable
H2.3		Medium	Acceptable	Acceptable	Tolerable
H2.4		Large	n/a	Acceptable	Acceptable
H2.5		Very large (i.e. Comparable to ancient Carne Creek slide)	n/a	Acceptable	Acceptable

Figure 5-8 the corresponding F-N plots.

The only hazard with an estimated unacceptable individual risk rating is H1.4 (large rockfalls) occurring in Section 3. This is broadly comparable to failure of the large boulder stack noted at Location A in Section 3 (West). Suitable risk mitigation strategies include (1) scaling or removal of specific unstable rock blocks; or (2) diversion of the track alignment to reduce workers exposure to the potential runout path. The next section provides further discussion on suitable risk mitigation strategies aligned with the *ALARP* principle.

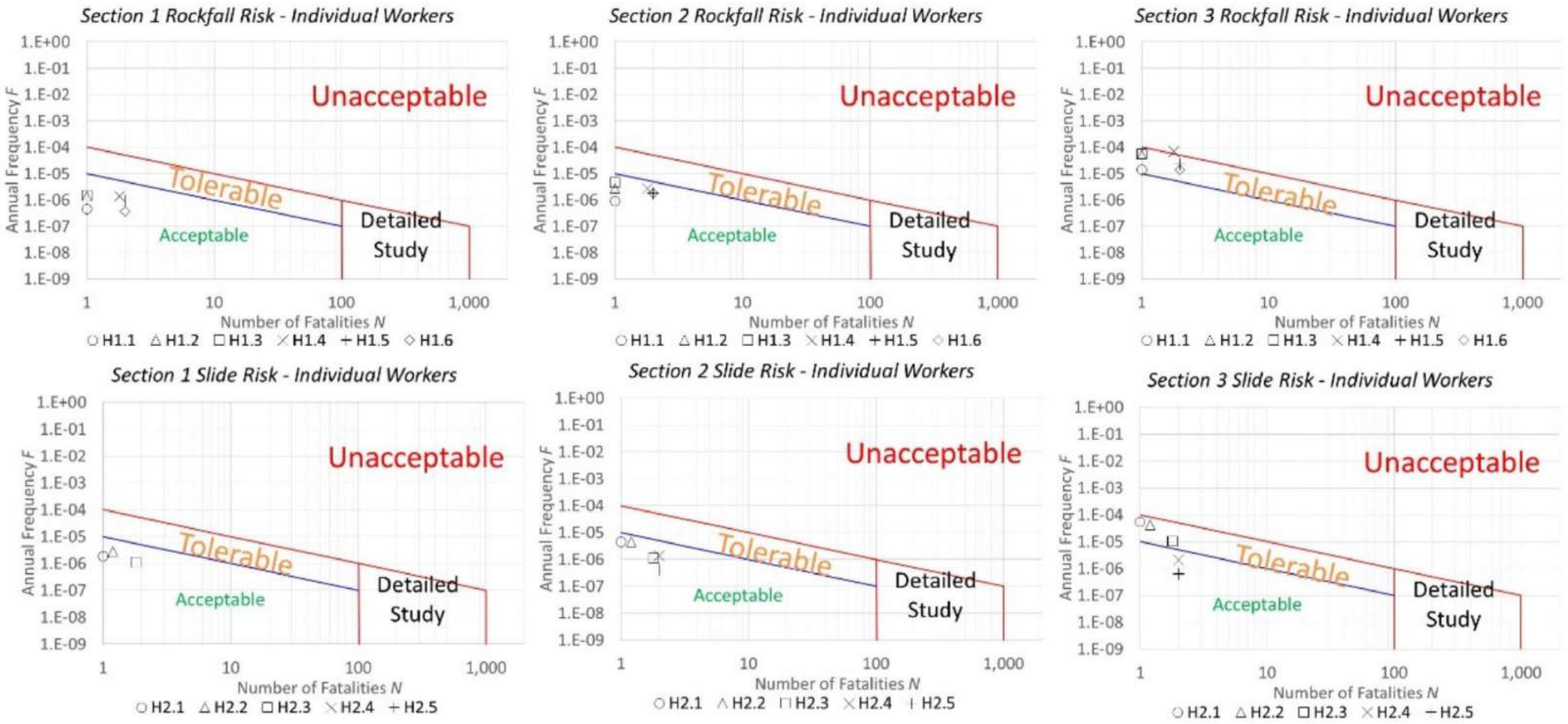

Figure 5-8: F-N plot of individual risk for track construction workers

6. Risk Mitigation Recommendations

Based on the generally "acceptable" to "tolerable" risk rating for most hazards, NPWS may choose to adopt an overarching suite of administrative controls to manage slope risk at the site, in lieu of cost-intensive and high-risk construction activities such as rock slope stabilisation, scaling (removal of unstable blocks), or construction of rockfall catch barriers.

Administrative controls on site access (such as a wet weather TARP protocol), risk communication strategies (e.g. landslide warning signage that reads "Landslide area: NO STOPPING" for the highest risk areas of Section 2 and Section 3, and a regime of regular track inspections by NPWS (nominally at intervals not exceeding 12 months) are suitable strategies to manage societal risk in accordance with the ALARP principle.

The Glow Worm area TARP previously prepared by Jacobs (2023) is expected to broadly applicable to the climatic environment of the project area. The recommended rainfall closure triggers are reproduced below:

≥ 30 mm in 24 hours	*Closure of track for 24 hours*
≥ 50 mm in 72 hours	*Closure of track for 72 hours*
≥ 100 mm in 7 days	*Closure of track for 5 days*
≥ 200 mm in 14 days	*Closure of track for 10 days*

For the Gardens of Stone Multi-Day Walk, unacceptable risk ratings only occur for hazard H1.4 (large rockfalls) in Section 3 under two scenarios:

- Long-term societal risk with 60,000 visitors per year
- Individual risk for workers based on a **300 day work program** covering the highest risk 3 km length of Section 3 encompassing the eastern and western approaches into the Wolgan Valley.

The total duration of the work program in Section 3 may be revised depending on route optimisation. **If the total work program in Section 3 can be reduced to 240 days, then the individual risk QRA produces a *tolerable* individual risk for hazard H1.4 in Section 3.**

Additional measures that could be undertaken to reduce the risk include:

- **Modify the route alignment** to avoid specific discrete rockfall hazards, **or scale loose detached blocks** that are located directly above the track before commencing works. The most notable specific example of this hazard is at location A near the western end of Section 3 (Figure 6-1).

Figure 6-1: Specific large rockfall hazard H1.4 at Section 3 (west)

To ensure that a *Tolerable* individual risk classification is achieved for all locations, track works through the identified sections of highest risk should include preliminary risk reduction works including:

(1) Inspection of the work site by NPWS staff to identify specific discrete blocks or landslide hazards above any work site.

(2) If hazards are identified, targeted scaling should be undertaken to remove loose boulders and debris from the slope immediately above the work site(s) prior to starting work.

(3) The work programme should be optimised to limit worker exposure time spent inside the "impact zone" of discrete landslide hazards.

(4) Workers should complete daily slope inspections to record any signs of instability.

(5) Workers should wear appropriate PPE at all times including hard hats or helmets on site.

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Appendix A. QRA Spreadsheets

Gardens of Stone Multi-Day Walk - Societal Risk at 30,000 visitors/year																				
Domain	Hazard Type	Hazard ID	Hazard Description	Annual Probability - $P_{(H)}$		Probability of Spatial Impact (Runout)	Temporal Spatial Probability - $P_{(T:S)}$						Vulnerability / Potential Loss of Life on Impact	Frequency of Impacts Causing a Fatality	Weighted Estimate of Fatalities		Risk Level	Annualised Life Risk R_{LoL}	Risk Mitigation Considerations	Mitigation Level (5)
				Estimated detachment frequency	Probability of detachment - $P_{(H)}$	$P_{(S:H)}$	Visitors Per Year	Impact Zone Length (m)	Annual Exposure Hours	Daytime 50% Reduction Factor	TARP Reduction Factor	$P_{(T:S)}$	$V_{(D:T)}$	$F = P_{(H)} \times P_{(S:H)} \times P_{(T:S)}$	Number of people present e_s	$N = e_s \times V_{(D:T)}$				
Section 1	Rockfalls initiating form escarpment cliffs	H1.1	Very small rockfalls (<0.01m3)	1 event every 10 years	0.100	0.1	30,000	1	10	0.5	50%	2.85E-04	10%	2.854E-06	1	1.0	Acceptable	2.854E-07	Regular inspections. TARP closures during heavy rainfall and after rockfalls or landslides are observed.	1
		H1.2	Small rockfalls (0.01 to 0.1m3)	1 event every 20 years	0.050	0.2	30,000	3	30	0.5	50%	8.56E-04	20%	8.562E-06	1	1.0	Acceptable	1.712E-06		
		H1.3	Medium rockfalls (0.1 to 1m^3)	1 event every 60 years	0.017	0.4	30,000	5	50	0.5	50%	1.43E-03	50%	9.513E-06	2	1.0	Acceptable	4.756E-06		
		H1.4	Large rockfalls (1 to 10m^3)	1 event every 200 years	0.005	0.6	30,000	10	100	0.5	50%	2.85E-03	90%	8.562E-06	2	1.8	Tolerable/ALARP	7.705E-06		
		H1.5	Very large rockfalls (10 to 100m^3)	1 event every 1000 years	0.001	1.0	30,000	20	200	0.5	50%	5.71E-03	100%	5.708E-06	2	2.0	Tolerable/ALARP	5.708E-06		
		H1.6	Rock mass collapse (>100m^3)	1 event every 5000 years	0.000	1.0	30,000	40	400	0.5	50%	1.14E-02	100%	2.283E-06	2	2.0	Acceptable	2.283E-06		
	Debris slides initiating on talus slope	H2.1	Very small debris slides (<100m^3)	1 event every 50 years	0.020	0.2	30,000	10	100	0.5	50%	2.85E-03	30%	1.142E-05	2	1.0	Tolerable/ALARP	3.425E-06		
		H2.2	Small debris slides (100 to 1000m^3)	1 event every 100 years	0.010	0.4	30,000	15	150	0.5	50%	4.28E-03	60%	1.712E-05	2	1.2	Tolerable/ALARP	1.027E-05		
		H2.3	Medium debris slides (1000 to 10,000m^3)	1 event every 1000 years	0.001	0.8	30,000	30	300	0.5	50%	8.56E-03	90%	6.849E-06	2	1.8	Tolerable/ALARP	6.164E-06		
		H2.4	Large debris slides (10,000 to 100,000m^3)	#VALUE!	n/a	n/a	30,000	60	600	0.5	50%	1.71E-02	100%	#VALUE!	2	2.0				
		H2.5	Very large debris slides (>100,000m^3)	#VALUE!	n/a	n/a	30,000	90	900	0.5	50%	2.57E-02	100%	#VALUE!	2	2.0				
Section 2	Rockfalls initiating form escarpment cliffs	H1.1	Very small rockfalls (<0.01m3)	1 event every 5 years	0.200	0.1	30,000	1	10	0.5	50%	2.85E-04	10%	5.708E-06	1	1.0	Acceptable	5.708E-07	Regular inspections. TARP closures during heavy rainfall and after rockfalls or landslides are observed.	1
		H1.2	Small rockfalls (0.01 to 0.1m3)	1 event every 10 years	0.100	0.2	30,000	3	30	0.5	50%	8.56E-04	20%	1.712E-05	1	1.0	Tolerable/ALARP	3.425E-06		
		H1.3	Medium rockfalls (0.1 to 1m^3)	1 event every 20 years	0.050	0.4	30,000	5	50	0.5	50%	1.43E-03	50%	2.854E-05	2	1.0	Tolerable/ALARP	1.427E-05		
		H1.4	Large rockfalls (1 to 10m^3)	1 event every 100 years	0.010	0.6	30,000	10	100	0.5	50%	2.85E-03	90%	1.712E-05	2	1.8	Tolerable/ALARP	1.541E-05		
		H1.5	Very large rockfalls (10 to 100m^3)	1 event every 500 years	0.002	1.0	30,000	20	200	0.5	50%	5.71E-03	100%	1.142E-05	2	2.0	Tolerable/ALARP	1.142E-05		
		H1.6	Rock mass collapse (>100m^3)	1 event every 1000 years	0.001	1.0	30,000	40	400	0.5	50%	1.14E-02	100%	1.142E-05	2	2.0	Tolerable/ALARP	1.142E-05		
	Debris slides initiating on talus slope	H2.1	Very small debris slides (<100m^3)	1 event every 20 years	0.050	0.2	30,000	10	100	0.5	50%	2.85E-03	30%	2.854E-05	2	1.0	Tolerable/ALARP	8.562E-06		
		H2.2	Small debris slides (100 to 1000m^3)	1 event every 60 years	0.017	0.4	30,000	15	150	0.5	50%	4.28E-03	60%	2.854E-05	2	1.2	Tolerable/ALARP	1.712E-05		
		H2.3	Medium debris slides (1000 to 10,000m^3)	1 event every 1000 years	0.001	0.8	30,000	30	300	0.5	50%	8.56E-03	90%	6.849E-06	2	1.8	Tolerable/ALARP	6.164E-06		
		H2.4	Large debris slides (10,000 to 100,000m^3)	1 event every 2000 years	0.001	1.0	30,000	60	600	0.5	50%	1.71E-02	100%	8.562E-06	2	2.0	Tolerable/ALARP	8.562E-06		
		H2.5	Very large debris slides (>100,000m^3)	1 event every 10000 years	0.0001	1.0	30,000	90	900	0.5	50%	2.57E-02	100%	2.568E-06	2	2.0	Acceptable	2.568E-06		
Section 3	Rockfalls initiating form escarpment cliffs	H1.1	Very small rockfalls (<0.01m3)	1 event every 1 years	1.000	0.2	30,000	1	10	0.5	50%	2.85E-04	10%	5.708E-05	1	1.0	Tolerable/ALARP	5.708E-06	Regular inspections. TARP closures during heavy rainfall and after rockfalls or landslides are observed.	1
		H1.2	Small rockfalls (0.01 to 0.1m3)	1 event every 2 years	0.500	0.5	30,000	3	30	0.5	50%	8.56E-04	20%	2.140E-04	1	1.0	Tolerable/ALARP	4.281E-05		
		H1.3	Medium rockfalls (0.1 to 1m^3)	1 event every 5 years	0.200	0.8	30,000	5	50	0.5	50%	1.43E-03	50%	2.283E-04	2	1.0	Tolerable/ALARP	1.142E-04		
		H1.4	Large rockfalls (1 to 10m^3)	1 event every 10 years	0.100	1.0	30,000	10	100	0.5	50%	2.85E-03	90%	2.854E-04	2	1.8	Tolerable/ALARP	2.568E-04		
		H1.5	Very large rockfalls (10 to 100m^3)	1 event every 60 years	0.017	1.0	30,000	20	200	0.5	50%	5.71E-03	100%	9.513E-05	2	2.0	Tolerable/ALARP	9.513E-05		
		H1.6	Rock mass collapse (>100m^3)	1 event every 200 years	0.005	1.0	30,000	40	400	0.5	50%	1.14E-02	100%	5.708E-05	2	2.0	Tolerable/ALARP	5.708E-05		
	Debris slides initiating on talus slope	H2.1	Very small debris slides (<100m^3)	1 event every 5 years	0.200	0.4	30,000	10	100	0.5	50%	2.85E-03	30%	2.283E-04	2	1.0	Tolerable/ALARP	6.849E-05		
		H2.2	Small debris slides (100 to 1000m^3)	1 event every 20 years	0.050	0.8	30,000	15	150	0.5	50%	4.28E-03	60%	1.712E-04	2	1.2	Tolerable/ALARP	1.027E-04		
		H2.3	Medium debris slides (1000 to 10,000m^3)	1 event every 200 years	0.005	1.0	30,000	30	300	0.5	50%	8.56E-03	90%	4.281E-05	2	1.8	Tolerable/ALARP	3.853E-05		
		H2.4	Large debris slides (10,000 to 100,000m^3)	1 event every 2000 years	0.001	1.0	30,000	60	600	0.5	50%	1.71E-02	100%	8.562E-06	2	2.0	Tolerable/ALARP	8.562E-06		
		H2.5	Very large debris slides (>100,000m^3)	1 event every 10000 years	0.0001	1.0	30,000	90	900	0.5	50%	2.57E-02	100%	2.568E-06	2	2.0	Acceptable	2.568E-06		
																Site Wide Annualised Life Risk		9.344E-04		

Notes on Table:

(1) All probabilities are annualised values

(2) Vulnerability values ($V_{(D:T)}$) refer to a person in open space at public areas or vehicles on access roads

(3) Vulnerability (Loss of life) values are generally adapted from the AGS Practice Note Guidelines for Landslide Risk Management 2007c

(4) Both the "Temporal Spatial Probability (P(T:S))" and the "No. of Individuals at Risk" have been calculated on data provided by NPWS

(5) Qualitative assessment of mitigation difficulty: Level 1 = easy, cheap, safe; Level 2 = some planning, moderate cost and risk; Level 3 = high cost and risk

Figure A- 1: Societal Risk QRA for 30,000 visitors per year

Gardens of Stone Multi-Day Walk - Societal Risk at 60,000 visitors/year																				
Domain	**Hazard Type**	**Hazard ID**	**Hazard Description**	**Annual Probability - $P_{(H)}$**		**Probability of Spatial Impact (Runout)**	**Temporal Spatial Probability - $P_{(T:S)}$**						**Vulnerability / Potential Loss of Life on Impact**	**Frequency of Impacts Causing a Fatality**	**Weighted Estimate of Fatalities**		**Risk Level**	**Annualised Life Risk R_{LoL}**	**Risk Mitigation Considerations**	**Mitigation Level (5)**
				Estimated detachment frequency	**Probability of detachment - $P_{(H)}$**	**$P_{(S:H)}$**	**Visitors Per Year**	**Impact Zone Length (m)**	**Annual Exposure Hours**	**Daytime 50% Reduction Factor**	**TARP Reduction Factor**	**$P_{(T:S)}$**	**$V_{(D:T)}$**	**$F = P_{(H)} \times P_{(S:H)} \times P_{(T:S)}$**	**Number of people present e_s**	**$N = e_s \times V_{(D:T)}$**				
Section 1	**Rockfalls initiating form escarpment cliffs**	H1.1	Very small rockfalls (<0.01m3)	1 event every 10 years	0.100	0.1	60,000	1	20	0.5	50%	5.71E-04	10%	5.708E-06	1	1.0	Acceptable	5.708E-07	Regular inspections. TARP closures during heavy rainfall and after rockfalls or landslides are observed.	1
		H1.2	Small rockfalls (0.01 to 0.1m3)	1 event every 20 years	0.050	0.2	60,000	3	60	0.5	50%	1.71E-03	20%	1.712E-05	1	1.0	Tolerable/ALARP	3.425E-06		
		H1.3	Medium rockfalls (0.1 to 1m^3)	1 event every 60 years	0.017	0.4	60,000	5	100	0.5	50%	2.85E-03	50%	1.903E-05	2	1.0	Tolerable/ALARP	9.513E-06		
		H1.4	Large rockfalls (1 to 10m^3)	1 event every 200 years	0.005	0.6	60,000	10	200	0.5	50%	5.71E-03	90%	1.712E-05	2	1.8	Tolerable/ALARP	1.541E-05		
		H1.5	Very large rockfalls (10 to 100m^3)	1 event every 1000 years	0.001	1.0	60,000	20	400	0.5	50%	1.14E-02	100%	1.142E-05	2	2.0	Tolerable/ALARP	1.142E-05		
		H1.6	Rock mass collapse (>100m^3)	1 event every 5000 years	0.000	1.0	60,000	40	800	0.5	50%	2.28E-02	100%	4.566E-06	2	2.0	Acceptable	4.566E-06		
	Debris slides initiating on talus slope	H2.1	Very small debris slides (<100m^3)	1 event every 50 years	0.020	0.2	60,000	10	200	0.5	50%	5.71E-03	30%	2.283E-05	2	1.0	Tolerable/ALARP	6.849E-06		
		H2.2	Small debris slides (100 to 1000m^3)	1 event every 100 years	0.010	0.4	60,000	15	300	0.5	50%	8.56E-03	60%	3.425E-05	2	1.2	Tolerable/ALARP	2.055E-05		
		H2.3	Medium debris slides (1000 to 10,000m^3)	1 event every 1000 years	0.001	0.8	60,000	30	600	0.5	50%	1.71E-02	90%	1.370E-05	2	1.8	Tolerable/ALARP	1.233E-05		
		H2.4	Large debris slides (10,000 to 100,000m^3)	#VALUE!	n/a	n/a	60,000	60	1200	0.5	50%	3.42E-02	100%	#VALUE!	2	2.0				
		H2.5	Very large debris slides (>100,000m^3)	#VALUE!	n/a	n/a	60,000	90	1800	0.5	50%	5.14E-02	100%	#VALUE!	2	2.0				
Section 2	**Rockfalls initiating form escarpment cliffs**	H1.1	Very small rockfalls (<0.01m3)	1 event every 5 years	0.200	0.1	60,000	1	20	0.5	50%	5.71E-04	10%	1.142E-05	1	1.0	Tolerable/ALARP	1.142E-06	Regular inspections. TARP closures during heavy rainfall and after rockfalls or landslides are observed.	1
		H1.2	Small rockfalls (0.01 to 0.1m3)	1 event every 10 years	0.100	0.2	60,000	3	60	0.5	50%	1.71E-03	20%	3.425E-05	1	1.0	Tolerable/ALARP	6.849E-06		
		H1.3	Medium rockfalls (0.1 to 1m^3)	1 event every 20 years	0.050	0.4	60,000	5	100	0.5	50%	2.85E-03	50%	5.708E-05	2	1.0	Tolerable/ALARP	2.854E-05		
		H1.4	Large rockfalls (1 to 10m^3)	1 event every 100 years	0.010	0.6	60,000	10	200	0.5	50%	5.71E-03	90%	3.425E-05	2	1.8	Tolerable/ALARP	3.082E-05		
		H1.5	Very large rockfalls (10 to 100m^3)	1 event every 500 years	0.002	1.0	60,000	20	400	0.5	50%	1.14E-02	100%	2.283E-05	2	2.0	Tolerable/ALARP	2.283E-05		
		H1.6	Rock mass collapse (>100m^3)	1 event every 1000 years	0.001	1.0	60,000	40	800	0.5	50%	2.28E-02	100%	2.283E-05	2	2.0	Tolerable/ALARP	2.283E-05		
	Debris slides initiating on talus slope	H2.1	Very small debris slides (<100m^3)	1 event every 20 years	0.050	0.2	60,000	10	200	0.5	50%	5.71E-03	30%	5.708E-05	2	1.0	Tolerable/ALARP	1.712E-05		
		H2.2	Small debris slides (100 to 1000m^3)	1 event every 60 years	0.017	0.4	60,000	15	300	0.5	50%	8.56E-03	60%	5.708E-05	2	1.2	Tolerable/ALARP	3.425E-05		
		H2.3	Medium debris slides (1000 to 10,000m^3)	1 event every 1000 years	0.001	0.8	60,000	30	600	0.5	50%	1.71E-02	90%	1.370E-05	2	1.8	Tolerable/ALARP	1.233E-05		
		H2.4	Large debris slides (10,000 to 100,000m^3)	1 event every 2000 years	0.001	1.0	60,000	60	1200	0.5	50%	3.42E-02	100%	1.712E-05	2	2.0	Tolerable/ALARP	1.712E-05		
		H2.5	Very large debris slides (>100,000m^3)	1 event every 10000 years	0.0001	1.0	60,000	90	1800	0.5	50%	5.14E-02	100%	5.137E-06	2	2.0	Tolerable/ALARP	5.137E-06		
Section 3	**Rockfalls initiating form escarpment cliffs**	H1.1	Very small rockfalls (<0.01m3)	1 event every 1 years	1.000	0.2	60,000	1	20	0.5	50%	5.71E-04	10%	1.142E-04	1	1.0	Tolerable/ALARP	1.142E-05	Regular inspections. TARP closures during heavy rainfall and after rockfalls or landslides are observed.	1
		H1.2	Small rockfalls (0.01 to 0.1m3)	1 event every 2 years	0.500	0.5	60,000	3	60	0.5	50%	1.71E-03	20%	4.281E-04	1	1.0	Tolerable/ALARP	8.562E-05		
		H1.3	Medium rockfalls (0.1 to 1m^3)	1 event every 5 years	0.200	0.8	60,000	5	100	0.5	50%	2.85E-03	50%	4.566E-04	2	1.0	Tolerable/ALARP	2.283E-04		
		H1.4	Large rockfalls (1 to 10m^3)	1 event every 10 years	0.100	1.0	60,000	10	200	0.5	50%	5.71E-03	90%	5.708E-04	2	1.8	Unacceptable	5.137E-04		
		H1.5	Very large rockfalls (10 to 100m^3)	1 event every 60 years	0.017	1.0	60,000	20	400	0.5	50%	1.14E-02	100%	1.903E-04	2	2.0	Tolerable/ALARP	1.903E-04		
		H1.6	Rock mass collapse (>100m^3)	1 event every 200 years	0.005	1.0	60,000	40	800	0.5	50%	2.28E-02	100%	1.142E-04	2	2.0	Tolerable/ALARP	1.142E-04		
	Debris slides initiating on talus slope	H2.1	Very small debris slides (<100m^3)	1 event every 5 years	0.200	0.4	60,000	10	200	0.5	50%	5.71E-03	30%	4.566E-04	2	1.0	Tolerable/ALARP	1.370E-04		
		H2.2	Small debris slides (100 to 1000m^3)	1 event every 20 years	0.050	0.8	60,000	15	300	0.5	50%	8.56E-03	60%	3.425E-04	2	1.2	Tolerable/ALARP	2.055E-04		
		H2.3	Medium debris slides (1000 to 10,000m^3)	1 event every 200 years	0.005	1.0	60,000	30	600	0.5	50%	1.71E-02	90%	8.562E-05	2	1.8	Tolerable/ALARP	7.705E-05		
		H2.4	Large debris slides (10,000 to 100,000m^3)	1 event every 2000 years	0.001	1.0	60,000	60	1200	0.5	50%	3.42E-02	100%	1.712E-05	2	2.0	Tolerable/ALARP	1.712E-05		
		H2.5	Very large debris slides (>100,000m^3)	1 event every 10000 years	0.0001	1.0	60,000	90	1800	0.5	50%	5.14E-02	100%	5.137E-06	2	2.0	Tolerable/ALARP	5.137E-06		
																	Site Wide Annualised Life Risk	**1.869E-03**		

Notes on Table:

(1) All probabilities are annualised values

(2) Vulnerability values ($V_{(D:T)}$) refer to a person in open space at public areas or vehicles on access roads

(3) Vulnerability (Loss of life) values are generally adapted from the AGS Practice Note Guidelines for Landslide Risk Management 2007c

(4) Both the "Temporal Spatial Probability (P(T:S))" and the "No. of Individuals at Risk" have been calculated on data provided by NPWS

(5) Qualitative assessment of mitigation difficulty: Level 1 = easy, cheap, safe; Level 2 = some planning, moderate cost and risk; Level 3 = high cost and risk

Figure A- 2: Societal Risk QRA for 60,000 visitors per year

Gardens of Stone Multi-Day Walk - Individual risk for workers

Domain	Hazard Type	Hazard ID	Hazard Description	Annual Probability - $P_{(H)}$		Probability of Spatial Impact (Runout)	Temporal Spatial Probability - $P_{(T:S)}$							Vulnerability / Potential Loss of Life on Impact	Frequency of Impacts Causing a Fatality	Weighted Estimate of Fatalities		Risk Level	Annualised Life Risk R_{LoL}	Risk Mitigation Considerations	Mitigation Level [5]
				Estimated detachment frequency	Probability of detachment - $P_{(H)}$	$P_{(S:H)}$	Program Days	Risk Domain Length	Impact Zone Length (m)	Exposure Hours	Daytime 50% Reduction Factor	TARP Reduction Factor	$P_{(T:S)}$	$V_{(D:T)}$	$F = P_{(H)} \times P_{(S:H)} \times P_{(T:S)}$	Number of people present e_s	$N = e_s \times V_{(D:T)}$				
Section 1	Rockfalls initiating form escarpment cliffs	H1.1	Very small rockfalls (<0.01m3)	1 event every 10 years	0.100	0.1	100	1,500	1	1.6	0.5	50%	4.57E-05	10%	4.566E-07	1	1.0	Acceptable	4.566E-08	Daily pre-work site inspections to look for slope instability. TARP closures. Optimise route to avoid runout zones of obvious rockfall hazards. Scale loose blocks above track.	2
		H1.2	Small rockfalls (0.01 to 0.1m3)	1 event every 20 years	0.050	0.2	100	1,500	3	4.8	0.5	50%	1.37E-04	20%	1.370E-06	1	1.0	Acceptable	2.740E-07		
		H1.3	Medium rockfalls (0.1 to $1m^3$)	1 event every 60 years	0.017	0.4	100	1,500	5	8.0	0.5	50%	2.28E-04	50%	1.522E-06	2	1.0	Acceptable	7.610E-07		
		H1.4	Large rockfalls (1 to $10m^3$)	1 event every 200 years	0.005	0.6	100	1,500	10	16.0	0.5	50%	4.57E-04	90%	1.370E-06	2	1.8	Acceptable	1.233E-06		
		H1.5	Very large rockfalls (10 to $100m^3$)	1 event every 1000 years	0.001	1.0	100	1,500	20	32.0	0.5	50%	9.13E-04	100%	9.132E-07	2	2.0	Acceptable	9.132E-07		
		H1.6	Rock mass collapse (>$100m^3$)	1 event every 5000 years	0.000	1.0	100	1,500	40	64.0	0.5	50%	1.83E-03	100%	3.653E-07	2	2.0	Acceptable	3.653E-07		
	Debris slides initiating on talus slope	H2.1	Very small debris slides (<$100m^3$)	1 event every 50 years	0.020	0.2	100	1,500	10	16.0	0.5	50%	4.57E-04	30%	1.826E-06	2	1.0	Acceptable	5.479E-07		
		H2.2	Small debris slides (100 to $1000m^3$)	1 event every 100 years	0.010	0.4	100	1,500	15	24.0	0.5	50%	6.85E-04	60%	2.740E-06	2	1.2	Acceptable	1.644E-06		
		H2.3	Medium debris slides (1000 to $10,000m^3$)	1 event every 1000 years	0.001	0.8	100	1,500	30	48.0	0.5	50%	1.37E-03	90%	1.096E-06	2	1.8	Acceptable	9.863E-07		
		H2.4	Large debris slides (10,000 to $100,000m^3$)	#VALUE!	n/a	n/a	100	1,500	60	n/a	0.5	50%	#VALUE!	100%	#VALUE!	2	2.0				
		H2.5	Very large debris slides (>$100,000m^3$)	#VALUE!	n/a	n/a	100	1,500	90	n/a	0.5	50%	#VALUE!	100%	#VALUE!	2	2.0				
Section 2	Rockfalls initiating form escarpment cliffs	H1.1	Very small rockfalls (<0.01m3)	1 event every 5 years	0.200	0.1	87	1,300	1	1.6	0.5	50%	4.58E-05	10%	9.168E-07	1	1.0	Acceptable	9.168E-08	Daily pre-work site inspections to look for slope instability. TARP closures. Optimise route to avoid runout zones of obvious rockfall hazards. Scale loose blocks above track.	2
		H1.2	Small rockfalls (0.01 to 0.1m3)	1 event every 10 years	0.100	0.2	87	1,300	3	4.8	0.5	50%	1.38E-04	20%	2.750E-06	1	1.0	Acceptable	5.501E-07		
		H1.3	Medium rockfalls (0.1 to $1m^3$)	1 event every 20 years	0.050	0.4	87	1,300	5	8.0	0.5	50%	2.29E-04	50%	4.584E-06	2	1.0	Acceptable	2.292E-06		
		H1.4	Large rockfalls (1 to $10m^3$)	1 event every 100 years	0.010	0.6	87	1,300	10	16.1	0.5	50%	4.58E-04	90%	2.750E-06	2	1.8	Acceptable	2.475E-06		
		H1.5	Very large rockfalls (10 to $100m^3$)	1 event every 500 years	0.002	1.0	87	1,300	20	32.1	0.5	50%	9.17E-04	100%	1.834E-06	2	2.0	Acceptable	1.834E-06		
		H1.6	Rock mass collapse (>$100m^3$)	1 event every 1000 years	0.001	1.0	87	1,300	40	64.2	0.5	50%	1.83E-03	100%	1.834E-06	2	2.0	Acceptable	1.834E-06		
	Debris slides initiating on talus slope	H2.1	Very small debris slides (<$100m^3$)	1 event every 20 years	0.050	0.2	87	1,300	10	16.1	0.5	50%	4.58E-04	30%	4.584E-06	2	1.0	Acceptable	1.375E-06		
		H2.2	Small debris slides (100 to $1000m^3$)	1 event every 60 years	0.017	0.4	87	1,300	15	24.1	0.5	50%	6.88E-04	60%	4.584E-06	2	1.2	Acceptable	2.750E-06		
		H2.3	Medium debris slides (1000 to $10,000m^3$)	1 event every 1000 years	0.001	0.8	87	1,300	30	48.2	0.5	50%	1.38E-03	90%	1.100E-06	2	1.8	Acceptable	9.901E-07		
		H2.4	Large debris slides (10,000 to $100,000m^3$)	1 event every 2000 years	0.001	1.0	87	1,300	60	96.4	0.5	50%	2.75E-03	100%	1.375E-06	2	2.0	Acceptable	1.375E-06		
		H2.5	Very large debris slides (>$100,000m^3$)	1 event every 10000 years	0.0001	1.0	87	1,300	90	144.6	0.5	50%	4.13E-03	100%	4.125E-07	2	2.0	Acceptable	4.125E-07		
Section 3	Rockfalls initiating form escarpment cliffs	H1.1	Very small rockfalls (<0.01m3)	1 event every 1 years	1.000	0.2	300	3,000	1	2.4	0.5	50%	6.85E-05	10%	1.370E-05	1	1.0	Tolerable/ALARP	1.370E-06	Daily pre-work site inspections to look for slope instability. TARP closures. Optimise route to avoid runout zones of obvious rockfall hazards. Scale loose blocks above track.	2
		H1.2	Small rockfalls (0.01 to 0.1m3)	1 event every 2 years	0.500	0.5	300	3,000	3	7.2	0.5	50%	2.05E-04	20%	5.137E-05	1	1.0	Tolerable/ALARP	1.027E-05		
		H1.3	Medium rockfalls (0.1 to $1m^3$)	1 event every 5 years	0.200	0.8	300	3,000	5	12.0	0.5	50%	3.42E-04	50%	5.479E-05	2	1.0	Tolerable/ALARP	2.740E-05		
		H1.4	Large rockfalls (1 to $10m^3$)	1 event every 10 years	0.100	1.0	200	3,000	10	16.0	0.5	50%	4.57E-04	90%	4.566E-05	2	1.8	Tolerable/ALARP	4.110E-05		
		H1.5	Very large rockfalls (10 to $100m^3$)	1 event every 60 years	0.017	1.0	300	3,000	20	48.0	0.5	50%	1.37E-03	100%	2.283E-05	2	2.0	Tolerable/ALARP	2.283E-05		
		H1.6	Rock mass collapse (>$100m^3$)	1 event every 200 years	0.005	1.0	300	3,000	40	96.0	0.5	50%	2.74E-03	100%	1.370E-05	2	2.0	Tolerable/ALARP	1.370E-05		
	Debris slides initiating on talus slope	H2.1	Very small debris slides (<$100m^3$)	1 event every 5 years	0.200	0.4	300	3,000	10	24.0	0.5	50%	6.85E-04	30%	5.479E-05	2	1.0	Tolerable/ALARP	1.644E-05		
		H2.2	Small debris slides (100 to $1000m^3$)	1 event every 20 years	0.050	0.8	300	3,000	15	36.0	0.5	50%	1.03E-03	60%	4.110E-05	2	1.2	Tolerable/ALARP	2.466E-05		
		H2.3	Medium debris slides (1000 to $10,000m^3$)	1 event every 200 years	0.005	1.0	300	3,000	30	72.0	0.5	50%	2.05E-03	90%	1.027E-05	2	1.8	Tolerable/ALARP	9.247E-06		
		H2.4	Large debris slides (10,000 to $100,000m^3$)	1 event every 2000 years	0.001	1.0	300	3,000	60	144.0	0.5	50%	4.11E-03	100%	2.055E-06	2	2.0	Acceptable	2.055E-06		
		H2.5	Very large debris slides (>$100,000m^3$)	1 event every 10000 years	0.0001	1.0	300	3,000	90	216.0	0.5	50%	6.16E-03	100%	6.164E-07	2	2.0	Acceptable	6.164E-07		
																	Site Wide Annualised Life Risk		**1.924E-04**		

Notes on Table:

(1) All probabilities are annualised values
(2) Vulnerability values ($V_{(D:T)}$) refer to a person in open space at public areas or vehicles on access roads
(3) Vulnerability (Loss of life) values are generally adapted from the AGS Practice Note Guidelines for Landslide Risk Management 2007c
(4) Both the "Temporal Spatial Probability (P(T:S))" and the "No. of Individuals at Risk" have been calculated on data provided by NPWS
(5) Qualitative assessment of mitigation difficulty: Level 1 = easy, cheap, safe; Level 2 = some planning, moderate cost and risk; Level 3 = high cost and risk

Figure A- 3: Individual Risk QRA for workers

Appendix B. GIS Maps

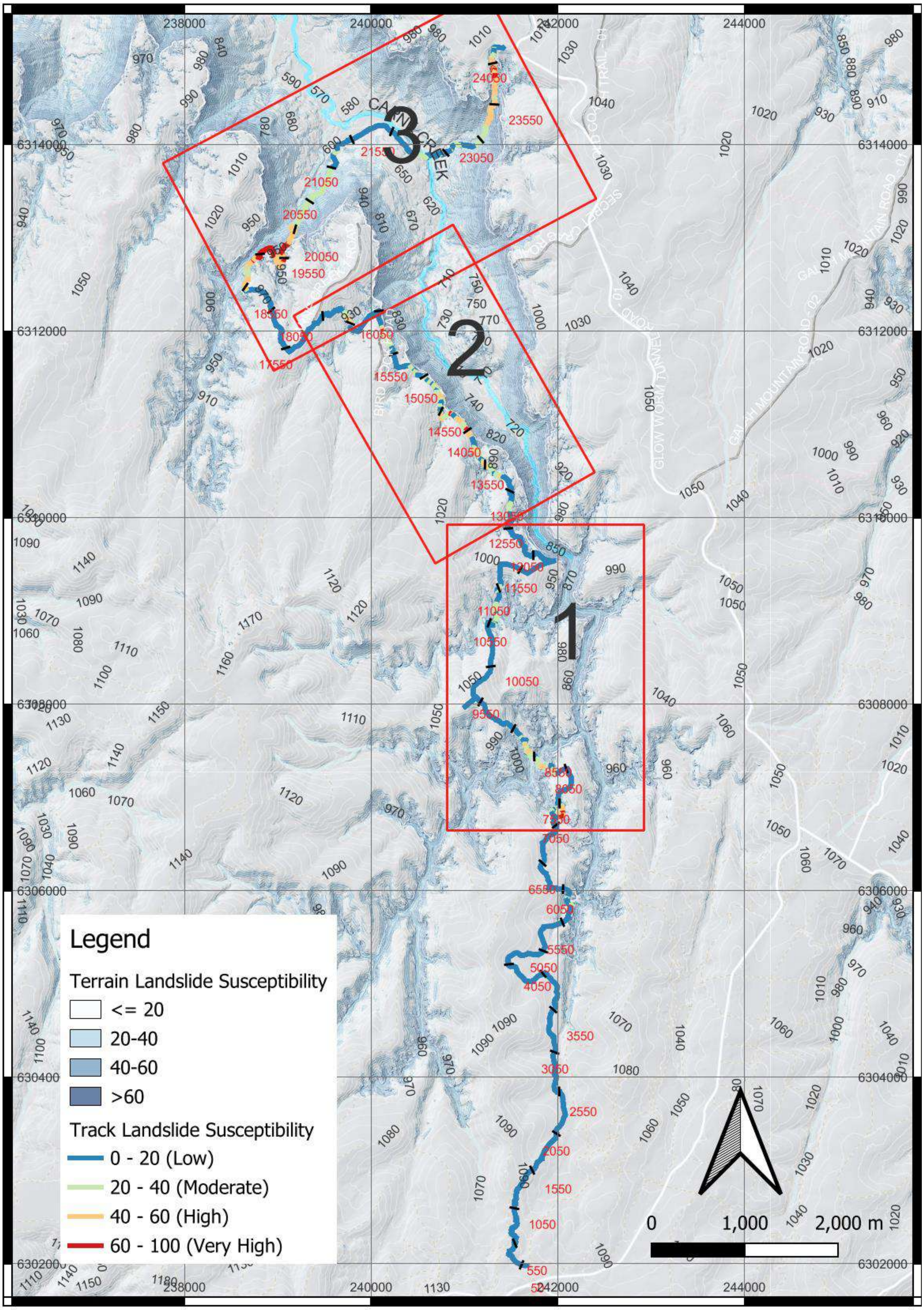

Figure B- 1: **Track wide landslide susceptibility map showing extent of insets 1, 2, and 3**

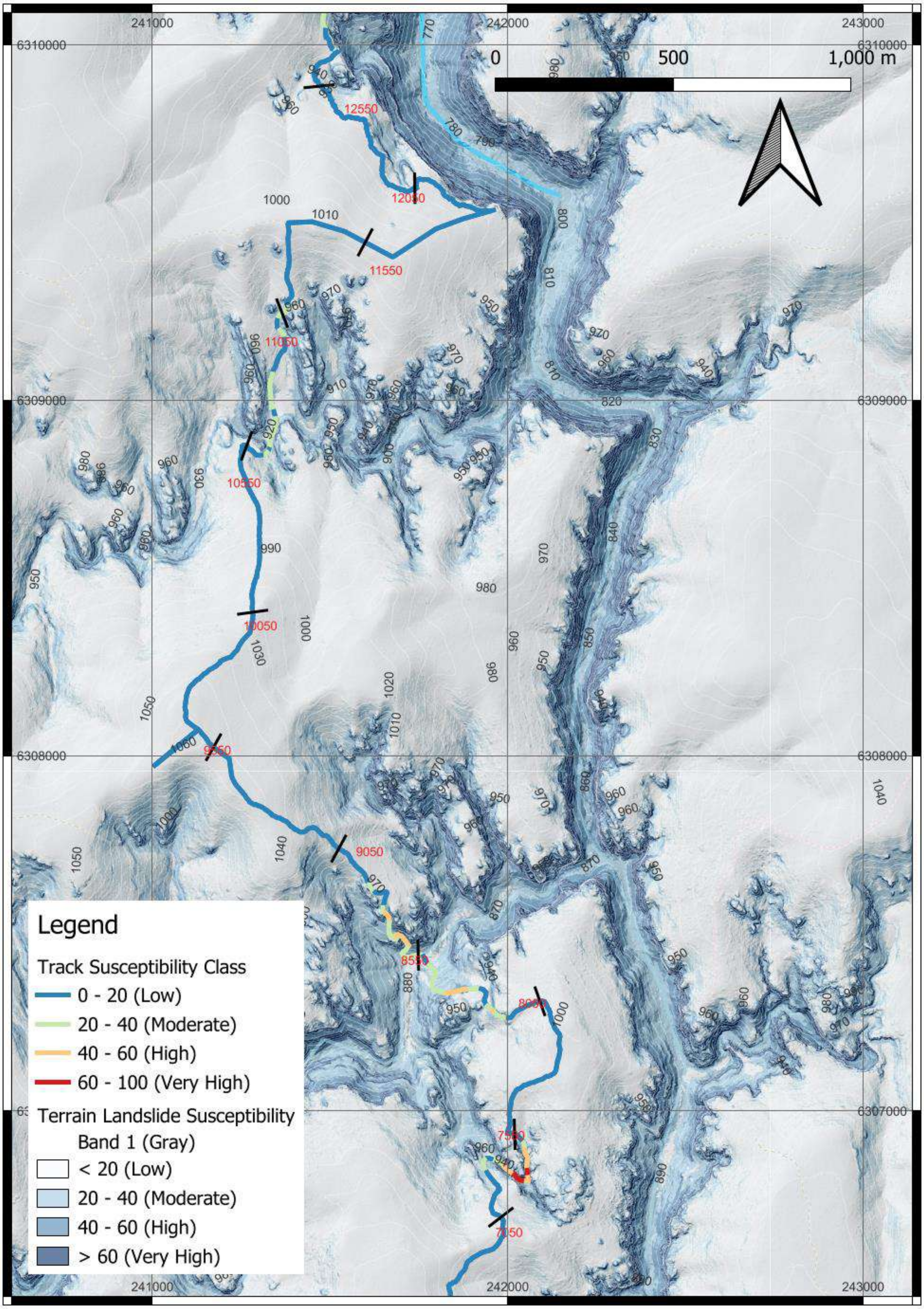

Figure B- 2: **Landslide susceptibility for inset 1 covering highest susceptibility zones of Section 1**

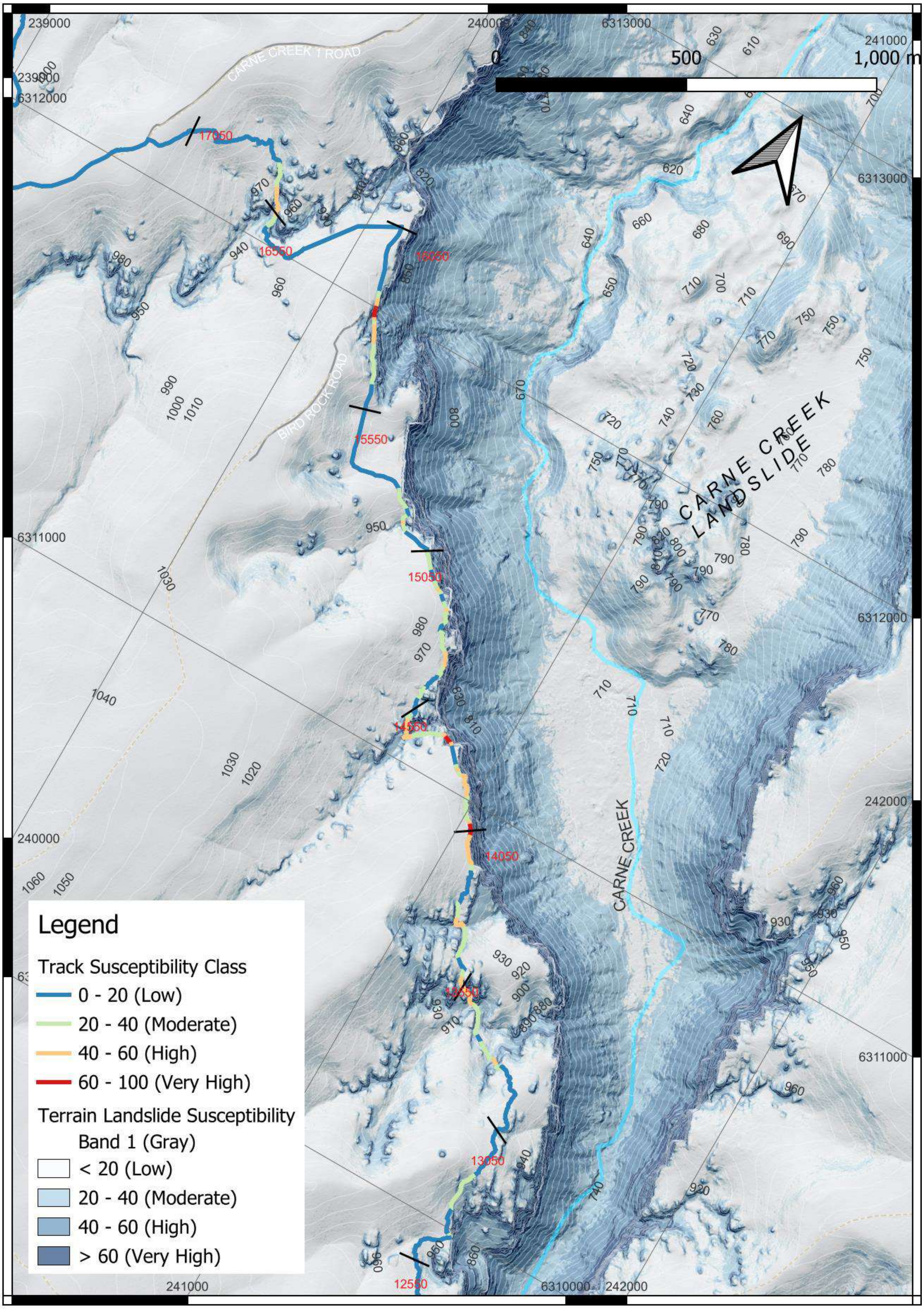

Figure B- 3: **Landslide susceptibility for inset 2 covering highest susceptibility zones of Section 2**

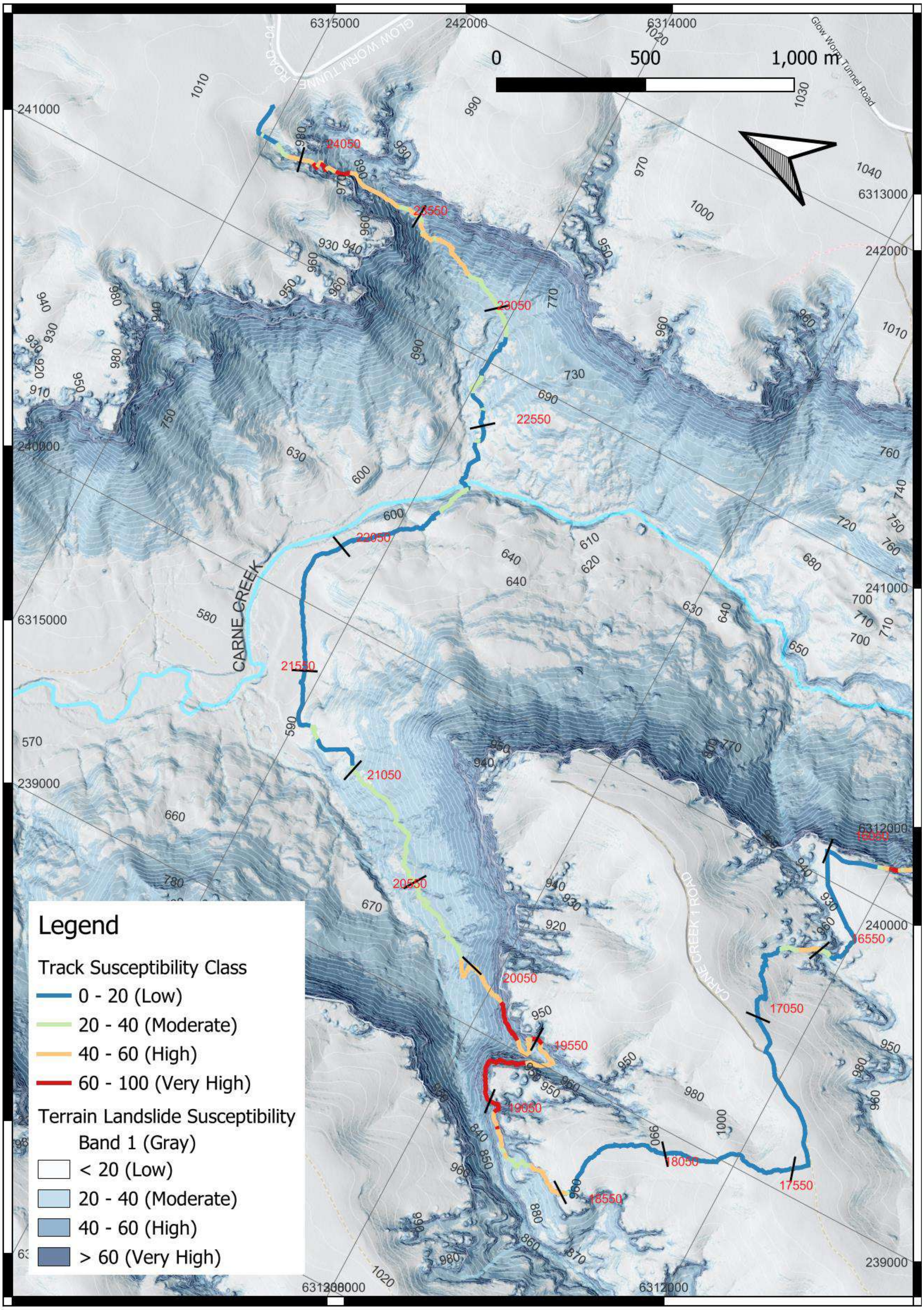

Figure B- 4: **Landslide susceptibility for insets 3 covering Section 3**

Appendix C –Tree risk management procedure (NPWS 2019)

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